

ASTM BULLETIN

260 SOUTH BROAD STREET

PHILADELPHIA, PA.

"Promotion of Knowledge of Materials of Engineering and Standardization of Specifications and Methods of Testing"

TELEPHONE—PENNypacker 3545

CABLE ADDRESS—TESTING

Number 94

October, 1938

A. S. T. M. Research Projects in 1938

Several New Projects Involve Properties of Materials; Methods of Testing

IT HAS been the practice to include in the October issue of the ASTM BULLETIN a review by Committee E-9 on Research of research activities being carried on by various committees of the Society or in collaboration with other groups. A complete list of the projects with brief discussion of each appeared in the 1937 October issue. The material given below covers generally only the new projects initiated during the current year. Reprints of the 1937 article will be furnished members or others interested, on request. Supplemented by the information given below, it presents a complete picture of the more than 140 projects involving research on the properties of materials and on methods of testing which are the divisions under which the projects are described.

RELATION OF RESEARCH AND STANDARDIZATION

From the very beginning, the importance of research in the Society's work has been recognized and it is significant that the original founders in preparing the statement of the purpose of the Society gave first, "promotion of knowledge of the materials of engineering" and then, "standardization of specifications and methods of testing." Obviously, research and standardization go hand in hand. Dr. C. B. Dudley, the Society's first president, and a pioneer in the development of specifications, after enumerating certain requirements of a workable specification for material, states that "above all it should embody within itself the results of the latest and best studies of the properties of the materials which it covers." Early recognition of this fact and its continued recognition through the years undoubtedly has contributed more basically than any other factor to the wide use and established authority of the Society's standards.

Painstaking investigation and study of experience accumulated over years of service are often required before an adequate specification can be prepared. Agreement must be reached on the properties of materials to be specified and methods of testing them. Due cognizance of manufacturing details, methods of inspection, and marking, should be given.

Largely it is this type of research which is being carried on by committees through the cooperative efforts of their members. Various types of research are recognized. One involves the correlation of existing data, a digest of it and the selection of the most important facts which are needed. Another type is that which involves extensive tests on materials, often the use of different kinds of tests to determine which give the most consistent results and are duplicated most easily in different laboratories.

There appeared in the December, January, and March BULLETINS interesting letters on the question of "fundamental" (or basic) research and "applied" research, giving various viewpoints on the question of how much A.S.T.M. should concern itself with so-called basic research. Some sources think that research on fundamentals is an essential part of our work. Others felt that this is not the case, but all agree that so-called applied research is a definite part of the Society's purpose.

While it is the purpose of this article primarily to enumerate new research projects initiated during the past year, attention should be called to the fact that very considerable progress has been made on a number of the researches started previously. A list of these would include: field corrosion tests of galvanized sheets, and coated hardware, structural shapes, etc.; various projects on effect of temperature on metals; atmospheric corrosion tests of non-ferrous metals and alloys; cement (mortar tests, autoclave soundness tests, methods of chemical analysis); concrete and concrete aggregates (relation of materials and mixtures to properties, permeability tests, conditions affecting durability in structures); methods of analysis of paint materials; electrical insulating materials (studies of tests for various properties and materials); rubber products (tension, abrasion, adhesion and other tests); textile materials (tests for various materials). There are several other projects where noteworthy advances have been made, in most cases detailed information being given in the respective committee reports.

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New Projects

Part I—Research on Properties of Materials

Where no reference is given to the Proceedings or preprints of current reports, the material given below covers essentially the information that is available.

Chilled and White Iron Castings (Committee A-3).—Investigation of the properties of these irons. Current work involves a study of the published literature on the testing of white iron and experimental work on transverse and tensile testing of chilled iron. Of related interest is a paper by S. C. Massari on "The Properties and Uses of Chilled Iron," presented at 1938 Annual Meeting.

Effect of Temperature on the Properties of Metals (Joint Research Committee of A.S.M.E. and A.S.T.M.).—Continuation of this extensive work in accumulating service data and developing standard procedures for tests at high and low temperatures. Project actively initiated during the year involves investigations of the properties of metals at low temperatures—a compilation of data is under way. Current report includes detailed discussion in appendices dealing with the following subjects: creep tests of tubular members; long-time creep tests of 0.35 per cent carbon steel (K20) (final report); cooperative creep tests on 0.35 per cent carbon steel at 850 F.; acceptability tests for high-temperature characteristics; effects of manufacturing variables on creep resistance of steels; see preprint, 1938 Report of Joint Committee.

The recently published *Volume on Creep Data* gives in the form of charts, tables and graphs the very extensive data developed by the committee covering large numbers of steels, non-ferrous metals, and other metallic materials used at high temperatures (864 pages).

Effect of Type of Testing Machines on Fatigue Test Results (Research Committee on Fatigue of Metals).—To obtain data which may aid in answering the question: "Are the shape of the S-N diagram and the endurance limit obtained from a set of fatigue tests a measure of a property of the metal, or are they affected by the type of machine used, and if so, how much?" Metals to be studied are: a heat-treated alloy steel and "as-rolled" low-alloy steel; possibly also an 8 per cent tin-bronze. Three types of machines to be used, with six laboratories cooperating. See preprint, 1938 Report of Research Committee.

Effect of Speed of Testing on Physical Properties of Metals (Committee E-1).—Studies of effect of different speeds of testing upon the yield point, ultimate strength, and other physical properties of metals. Results may be expected to form the basis of specifications requirements for testing speeds. Autographic records will show simultaneous records of time, strain and load from which the effect of rate of strain or rate of loading on test results can be determined. Tests to be conducted at University of Illinois.

Glazed Building Units (Committee C-15).—Study of the properties of commercial glazed building units; will include carrying out of laboratory tests. Tests being conducted in Ceramic Laboratory, Rutgers University, which is cooperating in the program.

Moisture Content of Paperboard and of Corrugated Fiberboard Containers (Committee D-6).—An extensive research program to secure data on the moisture content of container grades of paperboard and of corrugated fiberboard containers resulting from conditioning these products under several different procedures; and to determine the practicability of the methods of conditioning in relation to duplication of test results.

Part II—Research on Methods of Testing

Consistency of Paint (Committee D-1).—Method to be standardized for determining the consistency of enamel-type paints; consideration to be given in this work to the Stormer viscometer, Gardner-Parks mobilometer, A.S.T.M. consistency cup specified for nitrocellulose lacquers, and the Ford cup.

Painting of Structural Iron and Steel (Committee D-1).—Series of tests to be conducted, the object being to apply various chemical

inhibitive treatments and mechanical pre-treatments to steel and note the relative advantages or disadvantages.

Acid Heat of Gasoline (Committee D-2).—Results reported of cooperative tests of six laboratories on three samples of gasoline obtained by the use of the proposed method of test for acid heat of gasoline. Test method issued as tentative; see 1938 reprint pamphlet, "A.S.T.M. Standards on Petroleum Products and Lubricants."

Cubic Foot Weights of Crushed Bituminous Coal (Committee D-5).—Investigation of methods for determination of cubic foot weights of crushed bituminous coal. Test method to be developed that will give weights agreeing with those occurring in by-product coke ovens; see preprint, 1938 Report of Committee D-5.

Plasticity and Swelling of Coal (Committee D-5).—Studies of methods of testing expanding properties of coals during coke manufacture; series of different coals to be distributed to cooperating laboratories for test. Investigation of plastic properties of coals as affecting their combustion characteristics also being conducted.

Test Methods for Uniformity of Electrical Insulating Materials (Plates, Tubes and Rods) (Committee D-9).—Development of testing procedures for determining uniformity of the product. Extensive test program being prepared in cooperation with U. S. Navy Department. Accuracy and reproducibility of results being studied.

Chemical Analysis of Rubber Products (Committee D-11).—Investigation of a number of methods of chemical analysis, including colorimetric methods, for determination of small amounts of manganese and copper; data developed on various chemical and spectroscopic methods. Detailed report in preparation. Other chemical methods, including those for sulfur and carbon black are being studied; see preprint, 1938 Report of Committee D-11.

Tests (Physical, Chemical, Electrical) of Hard Rubber (Committee D-11).—Investigation of an extensive list of important properties of hard rubber in connection with work on standardizing testing procedures. Properties are classified in three groups: physical, chemical, and electrical. See preprint, 1938 Report of Committee D-11.

Sulfonated Detergents (Committee D-12).—As part of an extensive program involving studies and development of specifications and tests for soaps and detergents, cooperative laboratory work is in progress on method to evaluate sulfonated detergents by means of washing standard soiled cloth in a launderometer under varying conditions of temperature, solution concentration and alkalinity, and subsequently grading the wash towels by photometric readings.

Tests of Plastics (Committee D-20).—Development of test methods applicable to the finished products (molding materials, sheets, tubes and rods, and molded or fabricated articles) in the field of plastics. Following properties being studied: strength, hardness, thermal, optical and permanence. Round-robin series of tests contemplated involving thermal properties. See preprint, 1938 Report of Committee D-20. Symposium on Plastics (March, 1938) (available in published form) discusses properties and methods of determining them.

Recommended Practice for Dilatometric Analysis (Committee E-4).—Development of a method of procedure. Survey of present practices being made and opinions on various phases of the subject being obtained.

Felt (Committee D-13).—Part of a program involving wool and its products. Comprehensive program of work on felt is planned, including formulation of definitions and development of methods of test for permanent set, permanent recovery, dimensions of cut parts other than thickness, diameter of felt wicks, swell in cut parts and in flat sheet and roll felt, and materials soluble in water and in hydrochloric acid.

Methods of Testing Rayon Staple and Spun Rayon Yarns (Committee D-13).—Substantially as covered by title. Closely allied to project on tests of rayon and rayon fabrics. Methods of testing and tolerances for spun rayon yarns and threads issued as tentative; see compilation of "A.S.T.M. Standards on Textile Materials" (October, 1938).



New Specifications and Tests Approved

Standards Committee Acts at August Meeting

THE Society's Committee E-10 on Standards, at its meeting at Headquarters on August 25, approved for publication as tentative several proposed new specifications and test methods, accepted revisions to be incorporated immediately in 9 existing tentative standards and approved for publication as tentative changes in 11 formal standards. Of the new tentative standards, a number are essentially revisions of standards but because the changes are so extensive, they are being issued as new specifications. Many of these new and revised specifications and tests are of particular significance to the various industries to which they are directly related.

These actions by the Standards Committee are in accordance with the By-laws which provide that in the interval between annual meetings, standing committees may refer recommendations to Committee E-10. This method of approving new tentative standards was set up to expedite the issuance of important items and to take care of urgent cases where committees could not have the various details worked out in time to report at the annual meeting.

METALS

Recommendations of Committee A-1 on Steel involved particularly the field of pipe and tubing materials. One noteworthy change was to replace immediately the standard covering Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83-36) with a new tentative specification. The latter (A 83-38 T) is especially significant because it recognizes the advantages of designating wall thicknesses by decimals in place of B.w.g. and fractions as well as the desirability of indicating permissible variations for wall thickness and weight in percentages rather than by the existing dual system. The former grade of medium carbon material has been deleted and a new tentative specification for medium carbon seamless steel boiler tubes was approved (A 210-38 T). The demand for standardized requirements for carbon-molybdenum seamless steel boiler and superheater tubes resulted in new tentative specifications for this material (A 209-38 T).

A new specification (A 211-38 T) covers spiral welded steel or iron pipe 4 in. to 48 in. in diameter inclusive, with wall thickness from 1/16 in. to 11/64 in. manufactured by the following electric-fusion-welded processes: Spiral lap-welded joint, spiral lock seam welded joint, or spiral butt welded joint. In order to cover spiral welded material greater than 3/16 in. in thickness, tentative revisions are being published in two existing specifications covering electric-fusion-welded steel pipe of sizes from 8 in. to 30 in. and sizes 30 in. and over.

Intensive work on the part of the Society's Committee A-9 on Ferro-Alloys involving a complete review of nine existing specifications resulted in a number of extensive changes and reissue in the form of new tentative standards. The committee believes that the new specifications are truly representative of current commercial requirements. They cover the following: Spiegeleisen, ferromanganese, ferrosilicon, ferrochromium, ferrovandium, molybdenum salts and com-

pounds, ferromolybdenum, low-carbon ferromolybdenum and ferrotungsten.

To meet the demand for standard requirements for electrolytic cathode copper, new tentative specifications (B 115-38 T) were approved at the request of Committee B-2 on Non-Ferrous Metals and Alloys. The quality requirements provide that the copper shall have a minimum purity of 99.90 per cent, the silver being counted as copper. The copper is to have a resistivity not to exceed 0.15436 international ohms per metergram at 20 C. (annealed), the resistivity to be determined from a representative sample of each carload, or 50 tons, as a lot.

NON-METALS (LIME, CONCRETE, ASPHALT, RUBBER, TEXTILES)

Hydraulic Hydrated Lime.—For several years, Committee C-7 on Lime has been working on standard requirements for hydraulic hydrated lime. In the new tentative specifications (C 141-38 T) approved by Committee E-10, two types of lime are covered, namely, high calcium lime (containing not more than 5 per cent magnesium oxide) and magnesium lime (containing more than 5 per cent magnesium oxide). It is indicated that this lime may be used for scratch or brown coat of plaster, for stucco, for mortar, and as sole cementitious material in concrete, or in portland-cement concrete either as blend, amendment, or admixture.

Concrete Aggregates.—Since specifications for aggregate for concrete ordinarily include a limitation on clay lumps, Committee C-9 on Concrete and Concrete Aggregates has developed a test method for determining the amount of lumps in aggregate (C 142-38 T). This is a necessary complement to the existing specifications covering concrete aggregates (C 33-37 T). Requirements are given for taking the sample and this is then to be spread in a thin layer on the bottom of the container and examined for clay lumps. Any particles which can be broken into finely divided particles with the fingers shall be classified as clay lumps. After all discernible clay lumps have been broken, the residue from the clay lumps is to be removed by use of sieves which are specified. The percentage of clay lumps is then calculated to the nearest 0.1 per cent in accordance with a given formula.

Asphalt Plank.—The use of asphalt plank and consistent demands for standardized specification requirements led the Society's Committee D-4 on Road and Paving Materials to begin study several years ago of this material. This has just resulted in new specifications (D 517-38 T) covering plank of two types as used for bridge floors, namely, plain and mineral-surfaced. The plank is defined as a mixture of asphalt, fiber, and mineral aggregate formed by extrusion under sufficient pressure to expel the air and form a dense mass. The requirements in the specifications cover mineral filler, dimensions, absorption (not to exceed 1.0 per cent by weight), brittleness and indentation. Procedures are given covering brittleness and indentation tests.

Rubber Products (Light Aging).—Although tests for determining the resistance of rubber compounds to light checking and cracking are widely used, no standardized procedure



has been developed. Committee D-11 on Rubber Products after studying the best present practices has developed proposed methods which have been approved as a new tentative standard (D 518-38 T). The methods are for use in estimating the comparative ability of soft rubber compounds to withstand the effect of sunlight and weathering. They do not apply to the testing of material ordinarily classed as hard rubber. It is indicated that they are not suited for use in purchase specification requirements both because correlation with service life is uncertain and because the results from duplicate specimens tested in different locations do not check. No relation between the results of the tests and actual service performance is given or implied. The tests are principally of value when used for comparisons between two or more rubber compounds.

Wool (Fiber Length).—There has been a demand for a standardized method of test for fiber length of wool in loose form, top or roving and a method as developed by the wool section of Committee D-13 on Textile Materials has been approved. This method which has the designation D 519-38 T is also applicable to other fibers. The method gives requirements for sampling and conditioning and describes the apparatus which is required. Requirements are met by one of the commercial sorting machines now on the market. From the values obtained the average fiber length, standard deviation and coefficient of variation are calculated.

All of the new specifications and tests, and revisions will be published in the 1938 *Proceedings*, Part I, and also in the 1938 Book of A.S.T.M. Tentative Standards. As with all of the A.S.T.M. specifications, whether tentative or standard, they will also be available in separate form.

Including the new items listed below, there are now 365 tentative standards and 505 standards, a total of 870.

NEW TENTATIVE STANDARDS

Tentative Specifications for:

- Medium Carbon Seamless Steel Boiler and Superheater Tubes (A 210-38 T) *Committee A-1 on Steel*
- Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209-38 T) *Committee A-1*
- Spiral Welded Steel or Iron Pipe (A 211-38 T) *Committee A-1*
- Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83-38 T) *Committee A-1*. (Replaces immediately the existing standard.)
- Spiegeleisen (A 98-38 T) *Committee A-9 on Ferro-Alloys*
- Ferromanganese (A 99-38 T) *Committee A-9*
- Ferrosilicon (A 100-38 T) *Committee A-9*
- Ferrochromium (A 101-38 T) *Committee A-9*
- Ferrovandium (A 102-38 T) *Committee A-9*
- Ferrotungsten (A 144-38 T) *Committee A-9*
- Molybdenum Salts and Compounds (A 146-38 T) *Committee A-9*
- (The preceding seven specifications, when adopted, will replace the existing standards.)
- Ferromolybdenum (A 132-38 T) *Committee A-9*. (To replace, when adopted, the existing standards A 132-34 and A 145-34, Low-Carbon Ferromolybdenum.)
- Phosphor Tin (B 51-38 T) *Committee B-2 on Non-Ferrous Metals and Alloys*
- Phosphor Copper (B 52-38 T) *Committee B-2*
- Silicon Copper (B 53-38 T) *Committee B-2*
- Brazing Solder (B 64-38 T) *Committee B-2*
- (The preceding four specifications were reverted to tentative from standard, and revised.)
- Electrolytic Cathode Copper (B 115-38 T) *Committee B-2*
- Hydraulic Hydrated Lime for Structural Purposes (C 141-38 T) *Committee C-7 on Lime*
- Asphalt Plank (D 517-38 T) *Committee D-4 on Road and Paving Materials*
- Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11-38 T) *Committee E-1 on Methods of Testing*

Tentative Methods of Test for:

- Clay Lumps in Aggregates (C 142-38 T) *Committee C-9 on Concrete and Concrete Aggregates*
- Unit Weight of Aggregate for Concrete (C 29-38 T) *Committee C-9* (To replace, when adopted, the existing standard.)
- Resistance to Light Checking and Cracking of Rubber Compounds (D 518-38 T) *Committee D-11 on Rubber Products*
- Fiber Length of Wool (D 519-38 T) *Committee D-13 on Textile Materials*
- Chemical Analysis of Ferro-Alloys (E 31-38 T) *Committee E-3 on Chemical Analysis*. (Replaces immediately the standard methods A 104.)

REVISIONS IN EXISTING TENTATIVE STANDARDS (Incorporated immediately)

Tentative Specifications for:

- Seamless Steel Boiler Tubes for High-Pressure Service (A 192-38 T)
- Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194-38 T)
- Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111-38 T)

Tentative Methods of Test for:

- Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131-38 T)
- Films Deposited from Bituminous Emulsions (D 466-38 T)
- Sheet and Plate Materials Used in Electrical Insulation (D 229-38 T)
- Pin-Type, Lime Glass Insulators (D 468-38 T)
- Rubber Insulated Wire and Cable (D 470-38 T)
- Bend Testing for Ductility of Metals (E 16-31 T)

TENTATIVE REVISIONS OF STANDARDS (Not incorporated, but published for comment)

Standard Specifications for:

- Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134-36)
- Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not including 30 in.) (A 139-36)
- Welded and Seamless Steel Pipe (A 53-36)
- Billet-Steel Concrete Reinforcement Bars (A 15-35)
- Axle-Steel Concrete Reinforcement Bars (A 160-36)
- Aluminum-Bronze Castings (B 59-38)
- Clay Sewer Pipe (C 13-35)

Standard Methods of Test for:

- Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87-36)
- Hardness of Rubber (D 314-34)
- Standard Grain Size Chart for Classification of Steels (E 19-33)

Standard Definitions of Terms:

- Relating to Lime (C 51-28)

WITHDRAWAL OF TENTATIVE METHOD

Tentative Method of:

- Test for Saponification Number of Electrical Insulating Oils (D 438-37 T). (Revisions in the Tentative Methods D 94-38 T also covering saponification number test obviate the necessity of two procedures.)

1937 Reviews of Petroleum Technology

THERE has recently been published Volume 3 of the Annual Reviews of Petroleum Technology, covering 1937. This presents salient features of progress for the past year. It comprises a series of 27 critical surveys covering geology (general and regional), prospecting, drilling, production, transport, refining, cracking, testing and utilization. Motor fuels, heavy oils, lubricants, and asphaltic bitumen receive detailed treatment and an article on special products draws attention to the use of petroleum products in the electrical industry and the part played by pyrolysis and polymerization in the development of new synthetic compounds.

There are chapters on engines, motor benzole, hydrogenation, synthetic fuels and the carbonization of coal and other retortable oil-yielding materials.

In cloth binding, this 490-page volume can be obtained from the Institute of Petroleum, Aldine House, Bedford St., London, W. C. 2, England at 11s per copy.



Radiography in Industry¹

By H. H. Lester²

RADIOGRAPHY has had serious use in the metal industry for about sixteen years. It is no longer a new tool. In the beginning it was perhaps over-publicized and some misconceptions arose as to its power. There still exists a large lack of familiarity with it as a test method, and with its potential value as a development tool in the foundry. There have been misunderstandings and some incorrect applications, and no doubt a certain amount of exploitation in advertising propaganda. Notwithstanding these things, it has become so important in industry that the A.S.T.M., the first industrial society to recognize it, has set up a new standing committee, Committee E-7 on Radiographic Testing, devoted to its interests.

In connection with the launching of this body, it seems desirable to present a rather generalized picture of radiographic testing with particular reference to its possibilities and limitations, and to give some idea of the field of activity of this new standing committee.

This paper will be divided roughly along lines of division of the various subcommittees.

RADIOGRAPHY—A Rather Generalized Picture Somewhat Historical.

We are living in an age of mechanization. Modern industry demands continually better materials from which to build its various devices, including its engines of war.

Metals are the most important structural materials for the mechanical engineer. Metallurgists have improved them and their alloys to meet the necessities of industrial progress. But metals of fine intrinsic properties are not in themselves sufficient. It is necessary that structural units made from them shall be able to deliver in practical applications the service for which they were designed. This requires that parts like castings, or weldments, shall not be subject to unexpected failure.

A principal cause of unexpected failure is the presence, within the casting or weldment, of macroscopic defects such as cracks, voids, nonmetallic inclusions, or imperfectly fused portions of welds. We refer to these various defects as types of unsoundness. Radiography may be used to detect them and for this reason becomes a tool that can be used in the elimination of unsoundness. Hence, it may be stated as a generality that the basic reason for radiographing is the desire of industry, based on necessity or economy, for sounder structural units.

Although first used in the foundry, it has had its greatest development in the welding shops, and particularly those

shops devoted to the fabrication of pressure vessels. Fusion welding offers many advantages in the manufacture of these structures, which demand high joint efficiency and a very high order of service dependability. Unsoundness affects both of these desired qualities, especially the latter. Since radiography is peculiarly a test that reveals soundness conditions, it is regarded as an essential test in the manufacture of welded pressure vessels. The method finds application also in the non-destructive testing of other types of weldments where service dependability is of great importance. As a matter of fact, it has been used in the development and inspection of welds for gun carriages since 1928.

In the welding field, radiography has been in the hands of the producer. He uses it to develop procedures, to control shop practices, and to inspect the finished product for the benefit of the purchaser. J. C. Hodge has given a most excellent treatment of "Radiography in the Welding Shop," in a paper presented before the Society as a part of the 1936 X-ray Symposium.³ He points out that the recognition of X-ray tested welds by the Navy in 1930, and the addition of X-ray requirements to the A.S.M.E. Boiler Code in 1931, gave radiography its great impetus. In 1930, the first X-ray installation was made for the examination of welds exclusively. At that time there were five installations for other than pressure-vessel work. In 1936, at the time of the publication of Hodge's paper, there were thirty installations for the examination of pressure vessels and eighteen for other work. At the present time there are fifty-seven installations for pressure vessels and thirty-one for other work.

The situation with regard to the radiography of castings presents quite a different picture for which there are reasons, as we will try to show. A few of the larger companies own X-ray equipment and use the method in routine testing. The Army and Navy radiograph the products of their own foundries and also purchased materials. For the most part, foundry contacts with radiography have been in connection with acceptance tests conducted by or for the purchaser. These have been carried out in various commercial testing laboratories, or laboratories connected with educational institutions, except that gamma-ray inspection has been used extensively by both producers and consumers.

In one of the 1936 Symposium⁴ papers by Earnshaw Cook, on "Foundry Applications of Radiography," there is presented an accurate picture of the practical application of radiographic testing as it relates to the manufacture of castings. Attention is called also to a report by C. W. Briggs, Chairman of the Radiographic Committee of the American Foundrymen's Association and also of Subcommittee I on Radiography of Cast Metals of A.S.T.M. Committee E-7, that was presented before both of these groups in 1938. He addressed a questionnaire to 251 foundry organizations and received 49 replies. Nineteen of these had had experience with radiographic tests, fourteen of the nineteen occasional contacts, and only five were using them as a regular procedure. Twelve expressed the belief that the tests were instrumental in causing improvements in casting methods. Thirty-one stated that they hesitated to use the method, and twenty-one of these were hesitant because of a fear of incor-

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication, or for the attention of the author. Address all communications to Society Headquarters.

¹ Released for publication by the Chief of Ordnance, U. S. Army. Statements and opinions are to be understood as individual expressions of their author, and not those of the Ordnance Dept.

² Presented at the Forty-first Annual Meeting, Am. Soc. Testing Mats., Atlantic City, N. J., June 27-July 1, 1938.

³ Senior Physicist, Watertown Arsenal, Watertown, Mass.

⁴ Symposium on Radiography and X-ray Diffraction Methods, published by the American Society for Testing Materials, p. 53 (1936). (Symposium available as separate publication.)

⁵ *Ibid.*, p. 25.



rect interpretation of results. Twenty-seven thought the cost of equipment a deterrent, and twenty-one were fearful of the cost of personnel. On a question as to whether producers would take orders for castings subject to radiographic inspection, those who had had experience with the tests voted "yes" fourteen to two. Thirty-seven stated that they would use the tests to improve casting methods. The majority of those answering stated that they did not regard radiographic findings completely reliable. Nineteen failed to answer.

The questionnaire is notable for the painstaking care with which it was prepared and the thoughtfulness of the answers. It is disturbing to think that only about 2 per cent of the foundries are using¹ radiography in a routine manner. Since around thirty-one X-ray installations are devoted to other than pressure-vessel testing and since extensive use is made of X-rays, it appears that the radiography of castings, at least steel castings, is for the most part in the hands of consumers rather than producers. Inasmuch as there is a rather general acceptance of the fact that the tests are valuable for development and control purposes, it would seem that better results would be obtained if radiographic testing were in the hands of producers rather than consumers.

While this paper is not concerned with the history of these tests, the present section would be incomplete without mention of the valuable contributions of Mehl, Barrett, Doan, Briggs and Gezelius in the field of gamma-ray radiography. The development is distinctly American though a little work was done in Europe before Mehl started his experiments at the Naval Research Laboratory in 1928.

The employment of gamma radiation has extended the field of radiography greatly. Mochel has given a comprehensive review of gamma-ray applications in his excellent paper that formed a part of the 1936 X-ray Symposium.² For the purpose of recapitulation, it is pointed out that gamma rays are particularly valuable in examining large castings which, because of thickness of section or for other reasons, are beyond the scope of X-rays. Also, due to the low absorption coefficient of steel for these rays, varying thicknesses of metal, encountered frequently in castings, can be radiographed on the same film.

The present interest in this rapidly developing radiographic field is reflected in the two papers³ relating to this subject presented at this meeting. It might be of interest to quote a statement, pertinent to the growing use of gamma radiography, from a representative of the largest industrial user of radium, ". . . it has proved to be such a valuable tool that its abandonment would in my opinion be a calamity. It is increasing in use and its reception by the casting producers is becoming more and more cordial. Some idea of the extensive use being made by the Bureau of Construction and Repair (Navy) and by the Bureau of Engineering (Navy) is evidenced by the fact that we have added to our supply of radium until it now reaches the staggering total of 2.813 g. in eleven separate units. During February, 1938, we had a total of 1786 exposure hours. In March, 1938, we had a total of 2490 exposure hours.

"From the above it should be clear to you that we have obtained enormous benefit from the results of radiography. I honestly believe our ships are far more reliable because of the higher integrity of castings and other important stressed parts than were the older ships. . . ."⁴

Radiography of Castings

We have been speaking in rather general terms of the place of radiography in the testing of metal products. It was brought out in the 1936 Symposium, and again in the 1938 report to the A.F.A. Committee, that, in spite of obvious and admitted advantages, the makers of castings, with a few exceptions, are not using the method for development and control and are suffering financial losses in some cases due to the imposition of radiographic acceptance tests. It is a proper function of the radiographic committee to examine the causes for this situation and to suggest suitable remedies.

It is pointed out that, in spite of its sixteen years of use, it remains relatively unfamiliar to and is held in suspicion by a large part of the foundry industry. There are reasons for this. It is unfamiliar because that industry has not found it absolutely necessary to use it. The author pointed in a 1936 Symposium paper⁵ that radiographic tests may be applied to three general groups of castings: (a) those that are required to withstand high stresses; (b) those that, by virtue of the service they perform, must be very dependable; and (c) castings which require extensive machining. Other castings for special reasons outside of the above classifications may require radiographic study.

These groups constitute only a small part of the tonnage of iron and steel foundries, most of which is made up of relatively small and structurally unimportant units. Very large castings usually have metal sections that are beyond the reach of X-rays or even gamma rays and cannot be radiographed for this reason. There is another large volume of product represented in castings that have been developed gradually through years of production, that are perfectly satisfactory as they are, and that need no further development.

There is another group that could profit by X-ray development but because only a very few castings are made from a pattern, the cost of development cannot be absorbed easily. The manufacturer sees no economy in maintaining a radiographic plant for these special castings, and would hesitate anyway to undertake radiographic examination because if he charged development back to the customer his quotations would be so high that probably some one else would get the business. He does the next best thing. He manufactures as carefully as he can and takes a chance on X-ray acceptance tests—often to his final discomfort.

The above remarks refer mostly to cases where individual contracts are relatively small and to X-ray rather than to gamma-ray acceptance testing. Where large values are concerned, either because of the large number of castings concerned or because of the large size of individual castings, the manufacturer does make profitable use of radiographic information even though the tests may be performed by the customer. It is understood that manufacturers of Navy cast-

¹ Norman L. Mochel, "Gamma-Ray Radiography and Its Relation to X-ray Radiography," *Ibid.*, p. 116.

² Gilbert E. Doan and Shang-Shoa Young, "Gamma-Ray Radiography," *Proceedings, Am. Soc. Testing Mats.*, Vol. 38, Part II (1938).

Charles W. Briggs and Roy A. Gezelius, "A Study of Intensifying Screens for Gamma-Ray Radiography," *Proceedings, Am. Soc. Testing Mats.*, Vol. 38, Part II (1938).

³ This organization has increased its radium supply since the above statement was made. It now has 2965 mg.

⁴ H. H. Lester, "The Problem of Radiographic Inspection," *Ibid.*, p. 156.



ings have derived considerable benefit from radiographic studies made by Naval inspectors.

The foundryman is fearful of, or suspicious of, the tests partly because the tool is an unfamiliar one and partly because he has not been convinced that it is completely reliable. Mistakes have been made in interpretation and undue importance has been ascribed to relatively unimportant defects. These unhappy experiences have arisen quite largely if not altogether because of the fact that the radiography has been in the hands of the consumer and has been used to condemn poor castings rather than as a tool to construct good ones.

The above remarks present a rather negative picture. There is, however, another point of view. For the quality casting, radiography or its equivalent is in the picture to stay because industrial evolution is creating an ever greater market for highly stressed and highly dependable structural units. Due to the competition of weldments and other casting substitutes, improvements in the quality of his ordinary product is necessary and the bid of these structures for the quality market forces the foundryman to defend it. Radiography becomes a logical tool that can be used in the struggle to retain his share of the business. It will be used by the manufacturer for his own benefit, rather than against him as it now often is in acceptance testing.

There is a large problem in determining how radiography can be applied economically in the foundry. This will not be solved at once nor easily. It will require cooperative effort on the part of all interested. It would be a distinct help to industry if there were a special class, with appropriate subdivisions, set up for castings requiring high soundness characteristics. Standard radiographic specifications, acceptable to A.S.M.E., A.P.I., A.S.T.M. and A.F.A., should be worked out for this class. If this were done, those organizations supplying the products would no doubt make use of radiographic development. Committee E-7, working with the A.F.A., seems to be a logical place for the consideration of the problem.

It appears that perhaps the greatest stumbling block in the way of utilization of radiographic testing in foundries is the cost. Considering the nature of the equipment and the vast sums spent in scientific and engineering development of it, the cost of X-ray apparatus is reasonable at present. There is no great likelihood that it will be much less expensive. Apparatus is only part of the capital investment. The total cost installed with needed accessory equipment may be double that of the X-ray machine itself. The expense of operating adds considerable. But these costs represent only the expense of actually securing negatives.

Where the method is used for acceptance inspections, they may constitute most of the expense, but where the method is used for development, the actual cost of securing the negative is only part of the expense. The pictures must be studied carefully by the metallurgist or other responsible personnel. The necessity for intelligent study is to be emphasized because in it is involved the real return from the investment. The question of actual dollars spent is not so important as the question, "is the method worth the outlay?" The answer to this lies altogether in the value of the information derived and this depends quite largely upon the care in examining and interpreting films. While the need for careful study of radiographic evidence should be obvious, it is probable that those not actually doing the work realize how much is in-

involved. As an example, a company that manufactures heat-treating equipment is now making a radiographic study of its products with an idea that by eliminating unsoundness conditions known to exist, the service life can be increased. The group of pictures in Fig. 1 (next page) illustrates. A casting was taken from production for study and radiographed. Partly because the casting could not be held long since it was scheduled for shipment, a wooden framework, simulating the shape of the casting, was made and covered with semitransparent cloth to which the radiographs were attached. The pictures were attached to this model and illuminated from within. Defects are seen in relation to various structural details such as gates and risers, thick and thin sections, etc. *Probable causes must be deduced from the evidence of the negatives and a knowledge of all known metallurgical factors.* The model serves also to check effects of changes in casting procedure. Possibly I should stop describing the study at this point because, after considerable data had been secured, parts that had failed in service were examined and while the work is incomplete so far, no correlation has been found to exist between the failures and the regions of excessive porosity. In other words, controlling factors other than porosity are causing failure in this particular case.

Models serve well in studies of this kind, or defects may be chalked on the surface of the casting, but the point is to be emphasized that radiographic negatives must be analyzed with meticulous care and the results must be correlated with other information if the end desired is to be achieved. The procedure is necessarily expensive, but is almost sure to achieve the desired end if development is carried far enough.

For the study of castings, particularly large ones, gamma-ray radiography seems to be very promising. There is needed very little investment in plant, there is a relatively small outlay for the rental of radium, and the technique of taking pictures is well understood, thanks to the excellent pamphlet of Briggs and Gezelius.⁹ It is possible for the small manufacturer to use gamma rays where he could not afford to maintain an X-ray plant. It has disadvantages. One is the time it takes to get a picture. It is not a constant tool ready at call to get a quick picture of a casting that may be just out of the sand. For this reason it does not lend itself readily to development studies. However, with technical advances that are bound to come, its disadvantages will be lessened. With gamma-graphs, as with exographs, the cost of radiographing is not confined to the expense of obtaining the negatives; the major expense lies in the intelligent interpretation and metallurgical studies, only part of the information considered being contained in the pictures.

The author has heard at various times criticisms of the radiographic method that have seemed reasonable and that probably were justified but which were opinions rather than statements of fact. In order to get more evidence, he sent out some friendly inquiries in April of this year. Data or opinions based on actual observation were requested. Eighteen letters were sent out to selected consumers and producers who, in the opinion of the author, would be apt to have had the necessary experience to give authoritative answers.

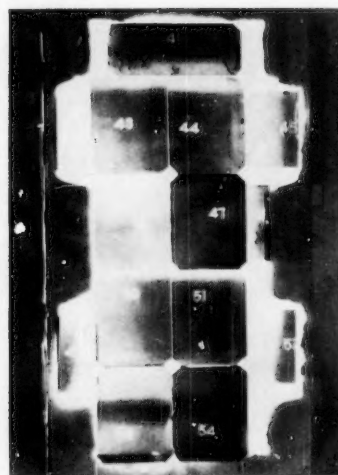
⁹ R. A. Gezelius and C. W. Briggs, "Radium for Industrial Radiography," The Radium Chemical Co., New York City, 1932.

See also G. E. Doan, "Gamma Ray Radiographic Testing," *Journal Franklin Institute*, Vol. 216, No. 2, August, 1933.

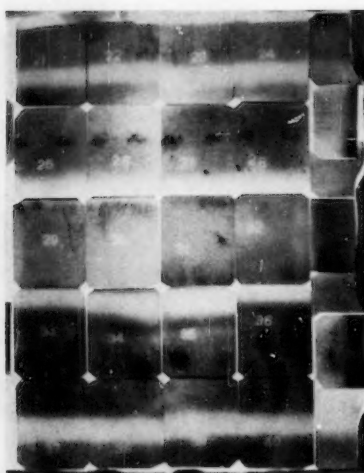




(a) The casting.



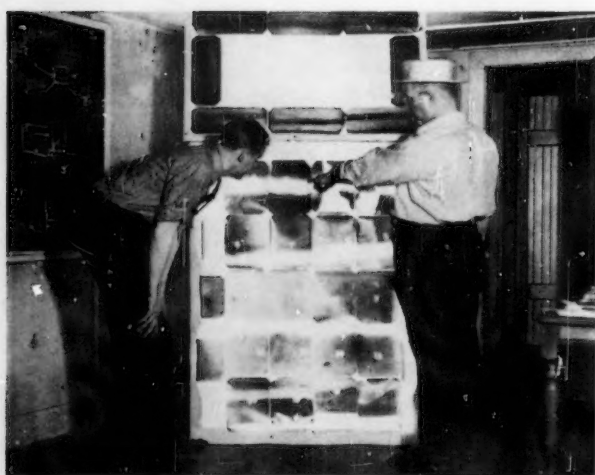
(b) Model with films attached. End view.



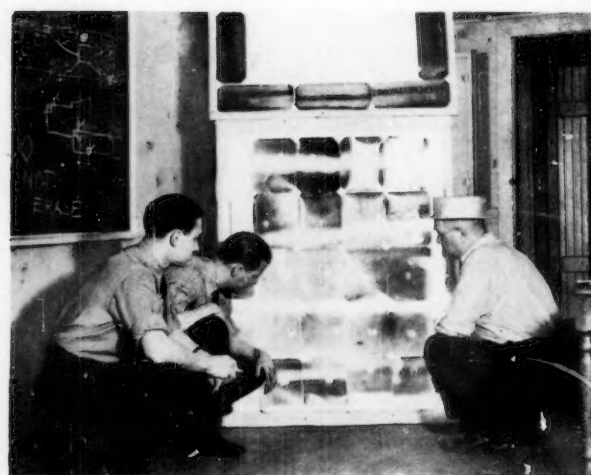
(c) Model - side view.
Showing porosity conditions.



(d) The laboratory explains
to the shop.



(e) The shop explains
to the laboratory.



(f) Study.

Fig. 1. - Radiographic Study of a Casting.

Fifteen replies were received. These have been broken down into form for easier presentation. Part of the questions refer to welding but are inserted at this place for convenience.

The letters were addressed to individuals that know from experience; however, the firm affiliations are listed rather than the individuals, for obvious reasons. In the analysis, the answers are split up into consumer and producer groups, but sometimes, as in the case of the Navy, an organization is listed in one place as a casting consumer and in another as a welding consumer, depending upon the context of his answer. The author has refrained from expressing his own answers to any of the questions, partly because the answers seem to be in all cases rather complimentary to radiography. The author's opinions would only swell the majority in each case.

Letters were addressed to individuals. The following list gives their company affiliations:

| | |
|-------------------------------------|---|
| American Brake Shoe and Foundry Co. | M. W. Kellogg Co. |
| Babcock & Wilcox Co. | Lebanon Steel Casting Co. |
| Bethlehem Steel Co. | U. S. Navy, Bureau of Construction and Repair |
| E. G. Budd Manufacturing Co. | U. S. Navy, Bureau of Engineering |
| Chapman Valve Co. | Standard Oil Development Co. |
| Crane Co. | Taylor Wharton Iron and Steel Co. |
| Ford Motor Co. | Union Carbon and Carbide Co. |
| General Alloys Co. | Westinghouse Electric and Manufacturing Co. |
| General Electric Co. | |
| Gulf Refining Co. | |

Question 1a:

Have you any data or opinions based on observation that defects for which castings would be rejected on radiographic test have consistently proven innocuous in service?

Answers:

| | |
|--------------------------|--------------------------|
| <i>Casting Producers</i> | <i>Casting Consumers</i> |
| "No"—7 | "No"—7 |
| "Yes"—1 | "Yes"—0 |
| <i>Welding Producers</i> | |
| "No"—1 | |
| Not answering—1 | |

Comments:

"In general, defects have been found to correspond with defective operation."

"We are quite convinced from evidence we are trying to complete that defects which might be cause for rejection are innocuous in service."

"No—I think, however, that sometimes castings are rejected for defects that do not justify rejection."

"No—But radiographically unsound castings have frequently failed in service."

"Emphatically no."

Attention is called to the phrasing of the question. We were seeking evidence rather than unguided opinion. The one "yes" answer was based on evidence obtained in the author's laboratory.

It is surprisingly evident that among people who have opportunity to observe, there have been almost no occasions to question the justice of radiographic rejections. The one "yes" answer happens to be one with which the author is familiar. This particular case has been used as an illustration

in another part of this paper. Defects did exist but there were other controlling factors which were more important.

Question 1b:

Have you any data or opinions based on observation that radiography has failed to reveal serious defects that have been found to be present by other means?

Answers:

| | |
|--|--------------------------|
| <i>Casting Producers</i> | <i>Casting Consumers</i> |
| "Yes"—2 | "Yes"—3 |
| "No"—4 | "No"—3 |
| | <i>Welding Producers</i> |
| "For sections too thick to radiograph"—1 | "Yes"—0 |
| | "No"—2 |

Comments:

"For fine cracks—yes." "Yes—due to poor radiographic technique." "For cracks and tears, 'yes,' due to difficulty of radiographing at a favorable angle." One casting producer cites the case of a gas leak through metal radiographically sound; in this case, no defect was found even on cutting and sectioning.

The answers to this question also are surprising. Tests have been performed by inexperienced and poorly trained operators. The technique of radiographic inspection has not been developed to its present state until recently. It is to be expected that mistakes, misinterpretations, and other accidents should occur, yet the preponderance of opinion seems to be that radiography has not failed to reveal defects found by other methods.

Question 1c:

Have you any data or opinions based on observation that defects in welds sufficient to cause rejection on boiler code or Navy standards (radiographic) are not serious enough to cause failure in service?

Answers:

| | |
|--------------------------|--------------------------|
| <i>Casting Producers</i> | <i>Casting Consumers</i> |
| "Yes"—1 | Not answering—1 |
| Not answering—1 | |
| <i>Welding Producers</i> | <i>Welding Consumers</i> |
| "No"—2 | "Yes"—3 (one qualified) |
| Not answering—1 | Not answering—3 |

Comments:

"I have repeatedly claimed present code or Navy standards are too severe."

"We can commercially obtain welds which meet the Navy standard. I see no reason why we should accept a lower standard."

Most of those interrogated did not answer this question for reasons that are obvious: that is, no one knows; as one put it, "time will tell." Opinion quoted reflects the producer and consumer points of view.

Question 1d:

Have you any data or opinions based on observations that radiography has failed to reveal existing defects that are of real seriousness?



Answers:

Casting Producers

"Yes"—1

"No"—2

Not answering—2

Welding Producers

"No"—3

"Yes"—0

Casting Consumers

"Yes"—1

"No"—3 (one answer
qualified)

Welding Consumers

"Yes"—2

"No"—1

Comments:

"The radiograph properly handled will reveal serious defects."

"Outside of fact mentioned in question 1b, no trouble has been experienced in inability to detect unsoundness."

"As far as I know, there is no case on record of failure due to defects that escaped radiographic detection."

"Method has failed to show full extent of defect."

"Our radiographs have not failed to show serious defects in castings."

"I do not know of a single instance where radiography has failed to show defects of real seriousness."

"Do not believe this to be true if proper technique is used."

This question overlaps question 1b. The repetition was partly for emphasis. The answers reflect a surprising confidence in radiographic findings.

Question 2:

What in your opinion are the chief limitations in radiographic tests? Expense? Sensitiveness? Misleading information? Other things?

Answers:

Expense—7; Sensitiveness—3; Misleading information—2;

Other things—

expense limits application to sample tests where 100 per cent tests would be better.

inconvenience; delay; misleading information depends on who has jurisdiction over the tests.

in development work, expense is not important; savings may justify; no difficulty with regard to sensitivity.

delay; lack of mobility; danger to personnel.

sensitiveness is not a limiting factor.

there are no chief limitations; sensitiveness far superior to older methods. No misleading information (from a large weld producer).

inertia of operating personnel; misconceptions of commercially sound castings.

interpretation of radiographic negatives; no appreciation of physical significance of radiographic defects.

difficulty of correlating defects with mechanical properties; manufacturers hate to go into radiography because they feel that it is a source of added trouble.

This question brought out an expected response. Many object to the expense of the test, yet only seven out of fifteen claimed expense as a major limitation. Some pointed out that expense in development work is a minor consideration. Others pointed to the fact that expense must be judged in terms of value received. The variety of limitations on other than the specifically suggested ones was unexpected. However, none of those suggested offer fundamental objections to the method.

Radiography of Welds

Industrial radiography using X-rays owes a great deal of its present advanced position to the makers of fusion welded pressure vessels who definitely invited radiographic acceptance tests, invested in X-ray equipment, and began to build to radiographic standards of soundness.

It would seem that Committee E-7 has little to offer to a group that is leading the field in radiography. However, in spite of the fact that producers and consumers alike seem to be well satisfied with the method as it is, there exist problems in standardization of procedures, in improvement of sensitivity, in evaluation of defects seen in radiographic negatives in terms of mechanical properties, and in other features that can very well be worked out through Subcommittee III on Radiography of Welds and Weldments, of Committee E-7.

Back as far as 1928, before the Navy and the A.S.M.E. recognized radiographically tested welds for boilers, the Army began making welded gun carriages based on radiographic control and inspection. The Navy has begun to use this type of construction more recently. There are other industrial applications of welding that call for radiographic development and control. The Army has asked recently for bids on welded bomb bodies calling for the highest grade of welding and specifying radiographic tests. There are, no doubt, other structures that demand equally high soundness characteristics.

There is needed, however, soundness standards for industrial welds that are based on actual data as to the effects of unsoundness conditions. The problem has been mentioned above and will be a consideration of Committee E-7 working with the nondestructive test subcommittee of the Welding Research group in the Engineering Foundation. Different requirements should be recognized for different types of work.

Unlike pressure vessels, where all parts are more or less equally stressed, most industrial structures do not require 100 per cent weld inspection. There are questions as to inspection procedures for these that should be recognized in recommended practices. There are questions involved in the use of radiography in the training and qualification of welders that could be considered by the committee with possible reduction to recommended practice.

In these possible activities, which are illustrative, fullest cooperation with other societies and with other interested bodies will be necessary and will be striven for.

Technical Research

Research for the purpose of improving the method is the responsibility of Subcommittee II on Technical Research, under the leadership of H. E. Seemann. This work is regarded as of the highest importance. Exquisite X-ray pictures of the delicate structures of a flower may be made that have the completeness and sharpness of detail of a fine photograph. But the X-ray pictures of metal greater than 1 in. in thickness are far from ideal when compared with the clarity and image detail in a good photograph. If better negatives could be made, the usefulness of the radiographic method would be greatly extended. One broad purpose of the subcommittee is the improvement of the quality of negatives. Four papers^{10, 11, 12, 13} directed toward this general end have been presented already by individuals of the subcommittee although it is less than a year old.

One of them¹⁰ is a study of metal intensifying screens. These lend themselves to a determination of the factors involved in intensification. The author discusses the two factors involved: (a) the direct action of electrons, and (b) the fluorescent radiation of the screen material, lead in this case. He devised an ingenious method of evaluating the two effects and obtained quantitative measurements. The radiation effect was shown to be due principally to the characteristic K radiation of lead. With the usual arrangement of front and back screens and double coated films it was found that the electron effect accounts for 84 per cent of the intensifying action for the front screen and 75 per cent for the back screen.

Another paper¹³ presented further studies of intensifying screens. In this case, lead screens and calcium tungstate screens were compared with regard to their efficiencies for gamma-ray radiography. The calcium tungstate screens were found to possess the advantage of greater speed, but the lead screens gave better images and were generally more consistent in their performance. The blackening of the film for the calcium tungstate screens did not vary according to an inverse square law with the distance from the source of radiation.

A third paper¹² dealt with the subject of proper film to source distance for different sized sources and different sized defects. The paper is pertinent because sharpness of images, particularly for small defects, is very much a function of the distances of film and source from the defect. For metal thicknesses of 2 in. and above, adjustments are difficult that will secure sharpness of image outline at the same time for defects near the outer and inner surfaces. The theory of the image formation from the point of view of geometrical optics is presented with excellent illustrations.

The fourth¹¹ paper deals with secondary radiation. This problem is probably the most important one in technical radiography that is up for solution at the present time. The blackening of the radiographic film is brought about by two factors—first, the direct contribution from the primary radiation that proceeds directly from the X-ray target and that alone is responsible for image formation, and second, the contribution from secondary radiation. The metal being radiographed absorbs part of the radiation proceeding from the X-ray tube. Part of the absorbed radiation reappears as heat in the metal but an appreciable amount appears as a re-radiation from the material. The re-radiation, known as secondary radiation, proceeds in various directions and is a contributing factor in the blackening of the film. It, in effect, produces a general fog over the film and tends to obscure image detail produced by the primary radiation. When the ratio of primary to secondary radiation is high, the obscuring fog is less apparent. When the ratio is low, fine image details are lost entirely.

The first contribution on the important problem in secondary radiation was contained in Mr. Seemann's 1937 paper¹⁰ referred to above. In it the author points out that the secondary radiation is ordinarily of longer wave length than the primary so that differential absorption of secondary and primary is possible. This is accomplished by means of filtering the radiation through lead which absorbs the longer wave length secondary preferentially to the shorter wave length primary.

The 1938 paper¹¹ is a continuation of the secondary radiation study. In it the author discusses the effects of secondary

radiation and describes a method of measuring it. In the experimental results it was found that in radiographing aluminum almost one-half of the secondary can be removed by filtering through lead. An almost linear relation was found to exist between the quantity of secondary and the thickness of the material. These results are to be regarded as preliminary ones. The final solution of the secondary radiation problem will most probably engage the attention of Subcommittee II for several years. Its complete solution, however, will greatly extend the usefulness of radiographic testing.

Technical research is of vital importance but investigative effort of a more practical nature is often equally so. A report to be presented in the near future to Subcommittee III illustrates the work of this group and also the cooperation with other radiographic committees that E-7 plans to make a major point of policy.

The A.S.M.E. and A.P.I. have a joint committee on the radiography of fusion welded joints. The personnel of this committee is largely represented in Subcommittee III of E-7. A recent problem before the A.S.M.E.-A.P.I. committee has been the consideration of a proper penetrometer for use in routine testing of class A-1 welds. This investigation has led to the proposal of a new device, a test block. A report of a two years' study involving six industrial laboratories was presented to the Joint Committee at a meeting held during the week of the 1938 A.S.T.M. annual meeting. A résumé of this report will be presented to A.S.T.M. through Subcommittee III of E-7 and action on the report paralleling that to be taken by the A.S.M.E. and A.P.I. will be sought. In this way there will be broader industrial recognition of the action of the Joint Committee and provision for more general uniformity in industrial practice.

Some important points in the report are summarized below.

A report presented in June¹⁴ concerned penetrameters and a test block. The penetrometer, hitherto prescribed in the code, is a piece of steel $\frac{1}{2}$ in. wide and arranged in steps $\frac{1}{2}$ in. long and of graded thicknesses so that the thickness of one step is 2 per cent of the thickness of the metal being radiographed. Each step contains a hole $\frac{3}{8}$ in. in diameter drilled through the $\frac{1}{2}$ in. square face. The device is placed alongside the weld being radiographed and its image appears in the negative. If the hole corresponding to the 2 per cent step shows, it is assumed that all cavities in the metal of equal or greater thickness dimensions are shown. It was supposed to be a sensitivity gage. In practice, it was discovered that cavities greater than 2 per cent sometimes did not show in the negatives although penetrometer holes corresponding to as low as $\frac{3}{4}$, or even $\frac{1}{2}$, per cent could be shown. There was objection also because the regular gradation of steps with the equal spacing of holes led to optical illusion,

¹⁰ H. E. Seemann, "Some Physical and Radiographic Properties of Metallic Intensifying Screens," *Journal of Applied Physics*, Vol. 8, No. 12, December, 1937.

¹¹ H. E. Seemann, "Secondary Radiation in the Radiography of Aluminum, Steel, and Lead," *Proceedings, Am. Soc. Testing Mats.*, Vol. 38, Part II (1938).

¹² Gilbert E. Doan and Shang-Shoa Young, "Gamma-Ray Radiography," *Loc. cit.*

¹³ Charles W. Briggs and Roy A. Gezelius, "A Study of Intensifying Screens for Gamma-Ray Radiography," *Loc. cit.*

¹⁴ Not published. A résumé will be presented as a report to Committee E-7 on Radiographic Testing of A.S.T.M. and will probably be available through that Society.



so that the 2 per cent image was often seen when it really was not visible.

The difficulty with this penetrameter was found to lie in the fact that the "area effect" was neglected. The discernibility of an image in the negative depends upon its blackness relative to the background, upon the sharpness of its outline, and upon its area. The holes in this penetrameter are too large.

The penetrameter has been regarded as more than a sensitivity gage. It has been the guarantee to the purchaser of the weldment that the picture in which it is seen was properly taken. There are differences in equipment, differences in technique, and differences in the skill or carefulness of operators. There is a question as to whether the penetrameter goes far enough in giving information as to correct radiographic procedures. Also, the penetrameter cannot be used easily as a sensitivity gage. A test block was suggested¹⁵ as a tool to supplement the penetrameter and as a device that could be used in studying many of the variables that enter into the clear depiction of radiographic images. A definition offered by the penetrameter subcommittee was,

"The test block is a device made up of carbon steel plates, some of which contain artificial defects, that may be used to determine whether or not a given radiographic equipment used according to a given procedure does in fact produce radiographic negatives of passable quality."

The use of the test block was defined elaborately, one clause specifying that

"The test block used with a properly selected penetrameter may be employed to determine the limits of sensitivity that can be obtained from the equipment and technique."

In another clause it is specified that

"... the sensitivity found with the test block shall not be regarded as equivalent to that obtained in routine testing where the results are affected by various factors such as difficulties in positioning, roughness of under surface, etc."

The above definitions are quoted from a report of the subcommittee to which the matters of the penetrameter and test block were referred. This subcommittee proposed a penetrameter of uniform thickness equal to 1 per cent and containing three holes whose diameters were 1, 2, and 4 per cent of the thickness of the metal to be tested.

A test block together with penetrameters of the type suggested were sent to six laboratories represented in the committee membership for study and experimentation. A set of nine experiments, involving different combinations of locations of defects in the test block, were carried out for the block built up to 1, 2, and 3-in. heights, respectively. These twenty-seven exposures were made in each laboratory. No restrictions were placed on the procedures except that the film to target distance was fixed at 30 in., and it was requested that the film density should be the same as that of a film supplied for the purpose of comparison. One laboratory tested with gamma rays as well as X-rays.

Each laboratory reported results in detail and, after completion of all of the tests, the films were assembled at one laboratory and analyzed by two men trained for negative reading. These men worked independently, each man reading all films. Differences of interpretation were settled with the assistance of a third man.

The smallest holes in the 1 per cent penetrameters were expected to be practically beyond the limits of detectability.

The results of the tests with the 2-in. block showed that no laboratory brought out the smallest hole, which was 0.02 in. deep and 0.02 in. in diameter. All except one showed the second hole (0.02 in. deep, 0.04 in. in diameter). One set of films showed the large hole (0.02 in. deep, 0.08 in. in diameter). It was surprising to find that the gamma-ray films showed the No. 2 hole of the 1 per cent penetrameter. No Bucky diaphragms were used in the 2-in. set-up but lead filters were used in at least one laboratory.

There were eight sets of films made in the 3-in. tests, one laboratory testing with and without the Bucky and one testing with both X-rays and gamma rays. Three sets were made using 400 kv.p. on the X-ray tube, two sets were made with 250 kv.p. and two with 220 kv.p. Two sets of films made with the assistance of Bucky diaphragm and using 400 kv.p. brought out the smallest hole in the 1 per cent penetrameter (0.03 in. deep, 0.03 in. in diameter). One using a Bucky and 400 kv.p. brought out the No. 2 hole (0.03 in. deep, 0.06 in. in diameter). Three who did not use a Bucky and 220 kv.p. brought out the No. 1 hole (0.03 in. deep, 0.12 in. in diameter). One set without Bucky and with 250 kv.p. did not show any holes in the 1 per cent penetrameter but did show the No. 3 hole in the 1.33 per cent penetrameter (0.04 in. deep, 0.04 in. in diameter). The gamma-ray films showed the No. 1 hole in the 1.67 per cent penetrameter (0.05 in. deep, 0.20 in. in diameter).

These results probably show the limits of sensitivity for industrial laboratories in this country. They are not practical limits. They show what can be done under very favorable conditions but not what one can expect under usual shop working conditions. The images of such small holes are too faint for easy detection, and they lack sharpness. Even those made with Bucky diaphragms were not satisfactory from this standpoint.

It was found necessary in order to get consistent readings, and indeed to see some of the images, to read the negatives in a darkened room supplied with illuminators equipped with controlled illumination. That is, all the light that came to the eye came through the film and its intensity was adjusted to the point of greatest acuity of vision. The film reading room is regularly equipped in this manner in some laboratories.

In addition to the penetrameters, the test block assembly included one plate that contained a crack system. This was made by laying down a weld under conditions that would cause cracking. The plate was then planed down to $\frac{1}{8}$ in. in thickness and cut so as to place the cracks in one corner. The weld cracked generously in a complicated pattern but few of the branches penetrated the complete thickness of the plate and due to the grinding most of them were rather shallow.

As was expected, the films for the 1-in. set-up detected the main crack system in its entirety except that the gamma-ray test revealed most but not all of it. There was a minor crack system separate from the main one at the junction of the weld with the plate metal that had been mostly removed in grinding. Four of the seven sets of films showed the greater part of this system. One 400-kv.p. set did not show it, the 250-kv.p. set and the gamma-ray set did not show it.

It was the general experience that as the crack system was moved closer to the film in its location in the test block there

¹⁵ The test block idea originated with C. A. Adams, Chairman of the A.S.M.E.-A.P.I. Committee on the Radiography of Fusion Welded Joints.



was an improvement in the definition. However, the definition was fairly good in both the remote and the near locations.

For the 2-in. test block arrangement, only the gamma-ray set of films failed to reveal any of the main crack system. One 400 kv.p. set showed nearly all of it, the others only the more important branches. None of the films showed any of the minor crack system.

For the 3-in. arrangement, the main branches of the principal crack system were shown in five of the eight sets of films submitted. The pictures taken with 400 kv.p. and Bucky diaphragms were superior to the others. The gamma-ray set showed none of the cracks. The 250 kv.p. set and one 220 kv.p. set also failed to show any of the cracks. Images were faint but the definition was fairly good. In this series, as with others, there was improvement of the pictures as the location of the cracks was moved closer to the film.

One question of importance in practical inspection relates to the ability of individual radiographic laboratories to produce radiographs of a quality that will insure that detectable defects are revealed. The inspector must have confidence in the negatives. The test block was intended to provide a method for determining the ability of a given laboratory to produce negatives of the quality required by inspection. The question, so far as the test block is concerned, resolves to whether this device can be used to rate the relative quality of the negatives produced in various laboratories.

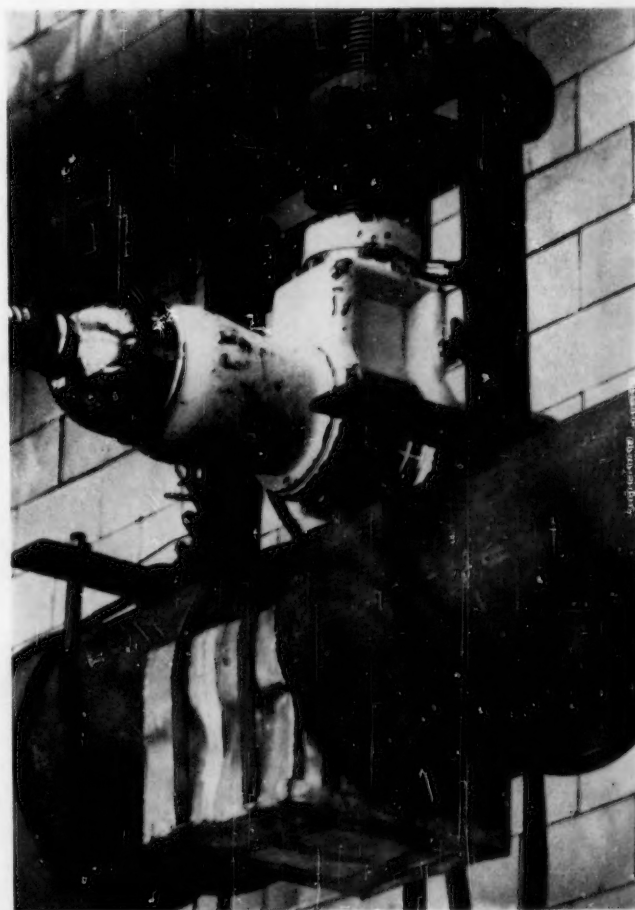
On the basis of the detectability of images, the various participating laboratories were given relative ratings as to the quality of their negatives. Judging by these ratings, one of the organizations that has the best obtainable equipment, highly skilled operators, and that takes justifiable pride in the quality of its work fell almost to the bottom of the list. This organization was the first one to perform the experimental tests, and carried them out in the spirit originally intended, that is, with the exact shop routine and without any additional care over what would be given to ordinary production work. As the test block went from place to place, there developed more and more a spirit of competition so that for the most part the ratings represented the best that each organization was capable of rather than the average quality that might be expected in production work. It is of value to determine the best possible results. From them one might qualify a laboratory in the sense that a welder is qualified, but they may be misleading to an inspector in that they do not indicate the actual sensitivities in the films that he is called upon to examine.

There are questions as to the possible abuse of the test block results in that by means of it, manufacturers might be held to unnecessarily high (and therefore unnecessarily expensive) standards of workmanship. For these and other reasons, the committee voted to refer the test block back to the subcommittee for further study.

The committee consideration of the penetrameter images obtained in the test block experiments led to the conclusion that the images of a 1 per cent penetrameter with a minimum 1 per cent diameter hole is much too difficult to use in practical work. It was concluded that the essential purpose of the penetrameter, namely, the assurance that the negative in which its image appears was made properly, could be ac-

complished as well with one whose images could be seen easily. The final recommendation specified a penetrameter made of material similar to that of the metal under test, the dimensions of which are $\frac{1}{2}$ in. wide, $1\frac{1}{2}$ in. long, of thickness equal to 2 per cent of the metal and containing three drilled holes whose diameters are, respectively, 4 per cent, 6 per cent, and 8 per cent of the metal thickness. Provisions were made for the appearance in the image of the positive identification of the penetrameter used.

In the foregoing there has been presented in broad outline the general aims and purposes of Committee E-7. Its reason for being, in common with other A.S.T.M. committees, is service to industry. Radiography is more than a method of testing. It is a device that makes possible the utilization of more economical methods of fabrication of highly responsible structures and that may be used to develop manufacturing procedures for the securing of essential soundness in cast products. It fills an essential need in modern industry in that it can be used to provide assurance of dependable service in the structural units of our mechanized society. Other than radiographic methods of nondestructive testing may develop greater importance. When they do, Committee E-7 will take cognizance of them. But until then, radiography remains as the most generally practical method of rendering its peculiar service. It is the mandate of Committee E-7 to assist in making this powerful tool most fruitful in its service.



Photograph by H. R. Isenburger, St. John's X-ray Service, Inc., awarded second prize in photographic exhibit at 1938 Annual Meeting.



New Standards on Construction Materials

DURING the current year, the Society has taken action on a number of specifications and tests which are of particular interest in the construction field, the standards covering materials which are widely used in such structures as buildings, highways, dams, pipe lines, and similar projects. Several new specifications cover materials for which there have not previously existed standardized requirements.

The use of standards as developed by the Society and other standardized bodies has been increasing steadily. Important new building codes, many of which embody the Society specifications as standards of quality covering various structural materials, have aided in stimulating their use, calling the attention of contractors, engineers and others to the standards. Several branches of the Government whose activities bring them into the field of construction are contributing to the use of standard specifications and tests.

Someone has said that one of the very important marks of a standard is that it is not the work of a single person but the result of enlightened cooperation. There is dissatisfaction with the lack of uniformity in some product or process and individuals or groups wish to avoid uncertainty and demand a compromise between conflicting interests so that energy can be better employed for other purposes. Standards, therefore, are an embodiment of the idea of cooperation, one of the foundations of modern society.

The standards issued by A.S.T.M. are the result of close cooperation of consumers, producers, and general interests who constitute the makeup of each of the Society's standing committees responsible for standardization activities in a specific field. The decisions made by representatives on these committees are based on the best available data and on a knowledge of production technique, and thus the specifications and tests are considered efficient. The very nature of a committee's organization, affording representation of the major interests concerned, makes the standards unbiased.

The list of specifications and tests which follows includes not only new ones first published this year, but also certain standards which have been formally adopted this year, and in a few cases items which were extensively revised this year. Anyone desiring a copy of the latest list of the 870 A.S.T.M. specifications, tests, definitions and recommended practices can obtain one without charge by writing to the Society Headquarters. All of the specifications listed below can be obtained in separate pamphlet form.

SPECIFICATIONS ISSUED, ADOPTED, OR REVISED IN 1938 COVERING CERTAIN STRUCTURAL MATERIALS

Metallic Materials

Specifications and Tests for:

- Structural Nickel Steel (A 8-38)
- Cast-Iron Culvert Pipe (A 142-38)
- Corrosion-Resisting Chromium Steels (Sheet, Strip and Plate) (A 176-38)
- High-Strength Corrosion-Resisting Chromium-Nickel Steels (Sheet and Strip) (A 177-38)
- Spiral Welded Steel or Iron Pipe (A 211-38 T)

Non-Metallic Materials

Specifications and Tests for:

- Portland Cement (C 9-38)
- High-Early-Strength Portland Cement (C 74-38)
- Curing Portland-Cement Concrete with Calcium Chloride Admixture (C 82-38)

- Curing Portland-Cement Concrete Slabs by Surface Application of Calcium Chloride (C 83-38)
- Ready Mixed Concrete (C 94-38)
- Making and Sorting Compression Test Specimens of Concrete in the Field (C 31-38)
- Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (C 78-38)
- Flow of Portland-Cement Concrete by Use of the Flow Table (C 124-38)
- Hydraulic Hydrated Lime for Structural Purposes (C 141-38 T)
- Clay Lumps in Aggregates (C 142-38 T)
- Unit Weight of Aggregate (C 29-38 T)
- Basic Sulfate White Lead (D 82-38)
- Blue Lead; Basic Sulfate (D 405-38)
- Asphalt Plank (D 517-38 T)

Report on Building Materials and Structures

THERE has recently been issued the first in a series of building materials and structures reports describing a program of research on building materials and structures for use in low-cost housing. This is issued through the National Bureau of Standards as a result of work recommended through the Central Housing Committee of the Government's housing agencies.

The introduction points out that progress in every modern industry depends on technical research to improve old products and to develop new ones, and that many believe progress in the building industry can come only by the same route. In order to stimulate this progress a new program is being formulated. This program is being administered and coordinated by division chiefs of the National Bureau of Standards, including Messrs. P. H. Bates, H. C. Dickinson, H. L. Dryden, W. E. Emley, G. E. F. Lundell, A. S. McAllister and H. S. Rawdon, with H. L. Dryden as chairman. The first report covers Objectives, Procedure, Scope, Cooperation with Industry, Detailed Programs, and includes a section pointing out that the National Bureau of Standards is a fact-finding organization and does not approve any particular material or method of construction.

The report summarizes the general objective of the program, as follows:

"To furnish to Government agencies, the building industry, and the public technical information from every available source on the engineering properties of building materials as incorporated in the structural elements and equipment of a house, with particular reference to low-cost housing and including new materials, equipment, and methods of construction as well as those already in use."

Copies of this report can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

1939 Marburg Lecture Committee Appointed

THE committee which will select the Edgar Marbury Lecturer for 1939 has been appointed. Under the rules governing the lecture, this group consists of a member of the Executive Committee, a member of Committee E-9 on Research and a member of Committee E-6 on Papers and Publications. The personnel, representing the respective committees in the order named, is as follows: A. E. White, Chairman, Director of Department of Engineering Research, and Professor of Metallurgical Engineering, University of Michigan; C. D. Holley, Director of Paint Research, The Sherwin-Williams Co.; and M. F. Skinner, Director of Research, Brooklyn Edison Co.



Important Considerations in Soil Mechanics

By C. A. Hogentogler¹ and Harold Allen¹

Two very important considerations which should receive the study of the Society in connection with its work in soil mechanics are:

1. That in dealing with the fine-grain soils we do not have just soil grains surrounded by free water, but instead soil grains encased in film water, with free water in the interstices between the films, and that the effective size of a particle is not that of the solids but of the solid plus the film in which the solid is encased.

2. That two special studies are urgently needed to determine (a) the significance of data furnished by shear tests and (b) to determine means of making the data more comprehensive.

FILM PHENOMENA

It has been suggested elsewhere² that in completely saturated soil, the soil particles may be considered as being encased in a film of adsorbed water and surrounded by free water as illustrated in Fig. 1. Free water has the freezing point, the boiling point, the surface tension, and the viscosity of ordinary water; adsorbed films, in contrast, have high boiling points, low freezing points, greater surface tension and are more viscous than free water. The properties of the outermost layer of adsorbed films of water are more nearly like those of free water, and the properties of the innermost layer are more nearly like those of solid water or ice. Within the thickness of the film, all the adhesive properties from those of free water to those of ice are present.

Therefore, instead of dealing with solid soil particles as such, we are concerned with the performance of the solid particles encased in their adsorbed films.

As a result, the size of particles indicated by sedimentation mechanical analyses, becomes the size of the particles plus film thickness instead of the size of the solids. The flow of water through soil likewise takes place between the films instead of the surfaces of the particles as such. Consequently, as a result the speed at which water percolates through soil, as well as the moisture contents indicative of some specific state of stability of soil vary wherever the thickness of the adsorbed films change.

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication, or for the attention of the author. Address all communications to Society Headquarters.

¹ Senior Highway Engineer, and Materials Engineer, respectively, U. S. Bureau of Public Roads, Washington, D. C.

Presented at the Forty-first Annual Meeting, Am. Soc. Testing Mats., Atlantic City, N. J., June 27-July 1, 1938.

² C. A. Hogentogler and E. A. Willis, "Essential Considerations in the Stabilization of Soil," *Proceedings, Am. Soc. Civil Engrs.*, Vol. 63, No. 6, June, 1937, p. 1035.

³ C. A. Hogentogler and E. A. Willis, "Subgrade Soil Testing Methods," *Proceedings, Am. Soc. Testing Mats.*, Vol. 34, Part II, p. 693 (1934).

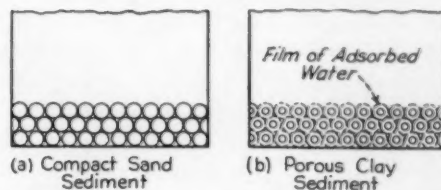


FIG. 1—Diagram of Sand and Clay Particles After Settling in Water.

The film theory can explain the high moisture contents of fine-grained soils. It is well known that sands settling out of suspension came to equilibrium in sediments with porosities of 30 to 33 per cent, that is, containing a solid content of two-thirds of the volume and a liquid content of one-third of the total volume of sediment. And for this to be true the grains must be for all practical purposes in contact with each other (see Fig. 1 (a)).

Clays, on the other hand, may come to equilibrium with a porosity such that the water content may be three or four times as great as the volume of the solids. Part of the higher porosities can be explained by differences in the shapes of clay and sand particles since dried and powdered clay soils

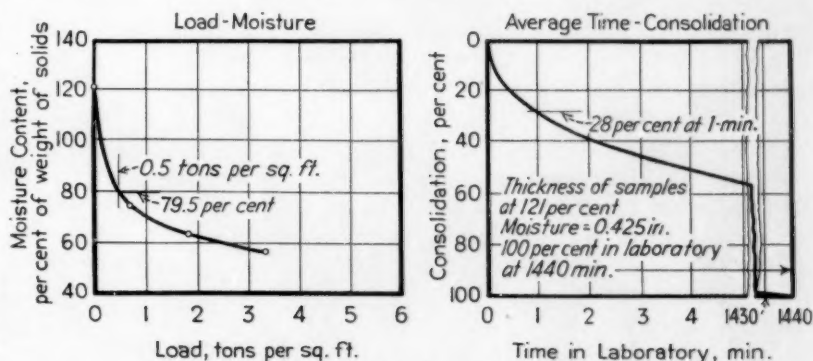


FIG. 2—Consolidation Test Results on Undisturbed Sample.

can have higher porosities than dry sands. However, the sediments formed by clay soils settling from suspensions may have voids ratios several times as great as those of the clay powders. Since the sand and the clay particles have approximately the same specific gravity which in turn is considerably greater than that of water, the clay particles in such cases must be held apart by films which are more viscous than the water through which the particles settle, and as shown by the broken lines in Fig. 1 (b) must have considerable thicknesses as compared with the size of the clay particles.

To illustrate the significance of the film theory in soil mechanics reference is made to Fig. 2, which shows the relation of moisture content to pressure for one clay sample as obtained in the compression test which has been presented before the Society.³

It will be noted that a pressure of 0.5 tons per sq. ft. will compress the sample to a moisture content of 79.5 per cent and that increasing the pressure to 1.5 tons per sq. ft. will reduce the moisture content to 66 per cent.



However, according to the theory of consolidation the water within the sample must carry all of the increased pressure at the instant the load is increased from 0.5 tons per sq. ft. to 1.5 tons per sq. ft. and this is gradually transferred to the soil grains, as the time of load application increases, until the soil grains carry all of the load when equilibrium has been reached between the pressure acting on the soil and the moisture content of the soil at 66 per cent.

That the soil solids could not carry the load of 1.5 tons per sq. ft. at a moisture content of 66 per cent without the assistance of water, becomes evident, because at this moisture content and with an assumed specific gravity of solids of 2.65, there is in the soil mass 1.75 times as much water as solids.

But if we consider that each clay particle is surrounded by film moisture attracted to the particle by a force which decreases as the distance from the surface of the particle increases, then the consolidation of clay soils becomes readily explainable, in that as consolidation proceeds the films separating the particles are reduced in thickness until equilibrium is established at a thickness of film where the attraction of the film to the particle is just sufficient to resist the stresses produced in the loaded soil.

The electrochemical properties of soil affect the film thickness. Consequently, as has been shown by Hans F. Winterkorn,⁴ the permeability, expansivity, and the amount and speed of the compression of a soil may be changed by the variation of the ions with which the soil is saturated.

This does not invalidate the data for practical uses provided proper attention is given to the chemical character of the water employed in testing the samples, but has to do principally with the interpretation of the shear as well as the compression test data. According to general assumption, the shear strength as determined on an immersed sample, having the compression characteristics as shown by the data, Fig. 2, would at a moisture content of 66 per cent and a normal pressure of 1.5 tons per sq. ft., depend upon the friction of grains sliding on grains. Instead it becomes evident from the above that such strength in colloidal material must be due to the friction of compressed films sliding on films.

SHEAR TESTS

Possibly more effort has been expended in attempts to develop satisfactory tests for disclosing the shear strength of soils than in the development of tests for determining any other soil properties. By many it is thought that the achievements attained by these efforts are still far from being satisfactory.

The authors share these views in part and appreciate the urgency of improving both apparatus and procedures with the aim of reducing experimental errors, but attribute the principal difficulties that have arisen in attempts to apply shear test data in practice to the manner of presentation and interpretation rather than to inaccuracies of the data.

The basic assumption involved in computing the shearing

resistance, s , of a sample of soil is Coulomb's law, expressed mathematically as

$$s = p \tan \phi + c$$

where s = shear stress or strength,
 p = pressure normal to shearing plane,
 ϕ = angle of internal friction, and
 c = cohesion.

The essential features of a simple type of test for determining the shear strengths of cohesive soils are shown in Fig. 3.

Essentially it consists of placing a thin layer of soil be-

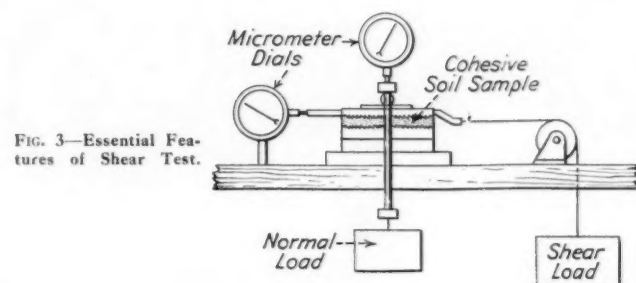


FIG. 3—Essential Features of Shear Test.

tween two rough surfaces and at a given normal load, drawing the one rough surface over the other by applied horizontal loads, until the soil layer fails. The surfaces may be encased in sides to form boxes with one face open; they may consist of metal or porous stones and the desired roughness of the face in contact with the soil sample may be furnished by means of corrugations and fins of various designs. The lateral movement of the upper surface or box, as the case may be, is considered as the horizontal deformation the sample undergoes during test and is measured by means of the micrometer dial.

A typical time-deformation curve for one soil sample, at one moisture content and under one normal load, resulting from the above operation, is shown in Fig. 4(a). The data for plotting the points on the curve were obtained by the application of equal shear load increments at 1½-min. inter-

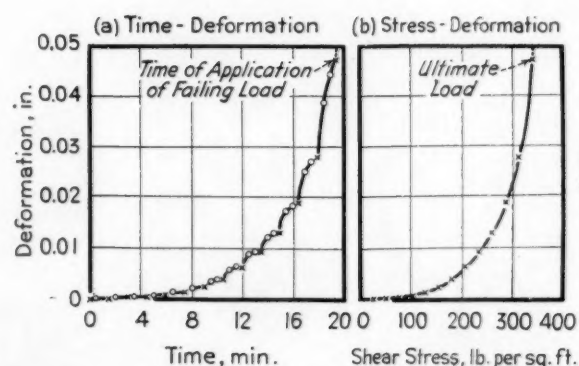


FIG. 4—Deformations in Direct Shear Test—Normal Load 145 lb. per sq. ft.

vals and the reading of the micrometer dial at ½-min. intervals. The crosses show the times at which load increments were applied. The circles show the deformations occurring between the application of load increments.

It will be noted that the increase in deformation was greatest during the first interval of time after the application of each new load up to the one causing failure. The load

⁴Hans F. Winterkorn, "Surface Chemical Factors Influencing the Engineering Properties of Soils," *Proceedings, Highway Research Board*, Vol. 16, p. 293 (1936).

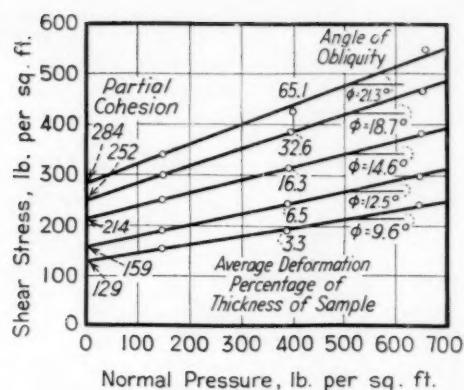


FIG. 5—The Relation of Normal and Shear Stresses for Variations in the Deformations.

which causes a constant or an accelerated rate of deformation is designated as the one causing failure.

The unit horizontal load applied before the one causing failure is designated as the ultimate shear strength. The area used in the calculation of the ultimate shear strength is the area of the sample at the shear plane when the load causing failure is applied. The relation of shear stresses to horizontal deformations of the sample for any constant normal load may then be shown as in Fig. 4(b).

The relation of shear strength to normal pressure is obtained by testing samples under different vertical loads and plotting the normal pressure against the corresponding shear strength. The shear strength - normal pressure relation for one soil is shown in the "ultimate" curve of Fig. 5. The other curves of Fig. 5 show the shear stress - normal pressure relations of the soil for deformations less than the ultimate. Each point on any particular curve is obtained by finding the stresses corresponding to a given percentage of the ultimate deformation recorded for the corresponding vertical load. The intercept of the curves with the vertical axis is indicated as the cohesion and the angle the curves make with the horizontal are designated as the angles of obliquity.

SIGNIFICANCE OF SHEAR TEST DATA

In considering the significance of shear test data, attention is called to the possibility that the c and ϕ as determined by test do not always conform to the usual definition of the constants. To illustrate, let us examine the phenomenon of shear in detail as shown in Fig. 6. If a shear load S is applied to a bar of steel, Fig. 6(a), a deformation will take place as shown in Fig. 6(b) (elastic). According to Ander-

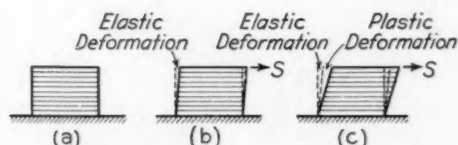


FIG. 6—Deformations Produced by Shear.

son,⁵ the bar may be considered to be made up of many horizontal layers of molecules, a few of which layers are

indicated in the sketch. Evidently, when the force S is applied and the bar is changed from the rectangular form to the sheared position, each layer is shifted to the right a slight distance s for the top, $\frac{1}{2}s$ for the middle, and so on. Furthermore, each layer is shifted or displaced very slightly with respect to the next layer below it, thereby causing a slight change in the relative positions of the molecules of successive layers.

If the bar were composed of soil, the layers of soil particles instead of molecules would be expected to slide on each other. Furthermore, the deformations could extend beyond the elastic range into the plastic range as shown in Fig. 6(c).

Reference is now made to cohesion which has been defined as that component of shear strength which is independent of the outside pressure acting on the soil, and to internal friction which has been defined as that component of shear strength which increases in direct proportion to the pressure, normal to the plane of shear.

Considering only the internal friction at this point, it can be seen that as the normal pressure is increased and the friction between the successive layers of soil is thereby increased, it would be expected that the shearing stress required to produce a given deformation of the soil sample would also be increased. In such case the stress-strain relations for two different normal pressures would have different slopes as shown in Fig. 7, left. Then the internal friction would conform to the definition as given above.

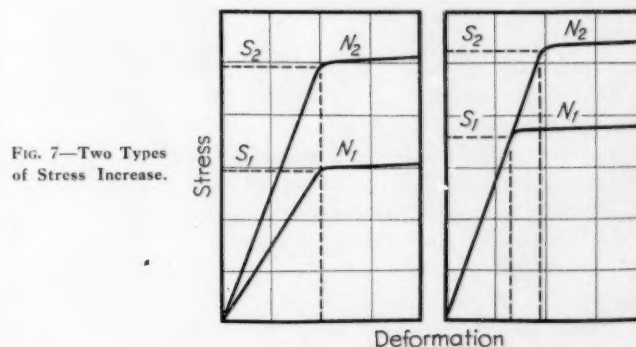


FIG. 7—Two Types of Stress Increase.

On the other hand, tests of soil materials show that increase in the shear strength may develop in another manner —by the sample undergoing greater deformation as the normal load is increased, as illustrated by the stress-strain curves, Fig. 7, right. It is believed that increase of strength attained in this manner would not satisfy the definition of internal friction as given above, but instead would indicate (1) that the indicated shear resistance is due to some binder action in addition to pure friction and (2) that the constant termed cohesion is also affected by the normal pressure. Figs. 8 and 9 show stress-strain relations obtained on two samples cut from sets of undisturbed cores of cohesive soil. The curves of Fig. 8 indicate the first type of strength increase noted above, whereas the curves of Fig. 9 show the second type. It is also interesting to note that negative values for the angle of internal friction for cohesive materials and negative values of cohesion for cohesionless materials have been obtained from tests made in accordance with the procedure described above.

Additive to the fact that the value of ϕ and c might not

⁵ William Ballantyne Anderson, "Physics for Technical Students in Colleges and Universities," McGraw-Hill Book Co., Inc., New York City (1925).



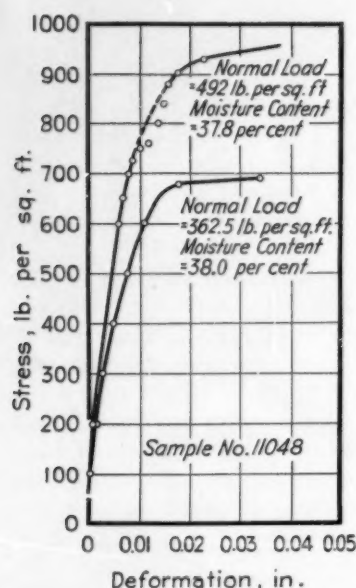


FIG. 8—Shear Stress—Deformation Curves Under Different Normal Loads.

satisfy the theoretical conception for these constants, there is also the possibility that the values of ϕ as determined by tests on cohesive soils may not have the same significance as the values of ϕ which are indicated by tests on cohesionless materials. This would conform to what has been learned from other tests such as the mechanical analysis, liquid limit, moisture equivalent and the like, wherein the test values for sands do not have the same significance as similar values for cohesive clays.

STRESS-STRAIN RELATIONS NEEDED

Difficulty has arisen from the meagerness of the shear test data generally used. Design data for utilizing all other engineering materials include stress-strain relations which show ultimate strengths and deformations at which failures occur and, furthermore, the relations of stress to deformation for all deformations smaller than the ultimate.

The pressure-deformation relation furnished by the compression tests on soils (see Fig. 2) is in effect such a stress-strain curve for the vertical consolidation of soils. But in the case of shear tests it has been generally customary to consider principally the ultimate shear strength together with the angle of internal friction and the cohesion on which the ultimate shear strength depends. To serve design purposes, this information should be supplemented by a complete shear stress-strain relation for deformations less than the ultimate.

There might be a number of ways of arranging shear test data in the form of shear stress-strain curves. The validity

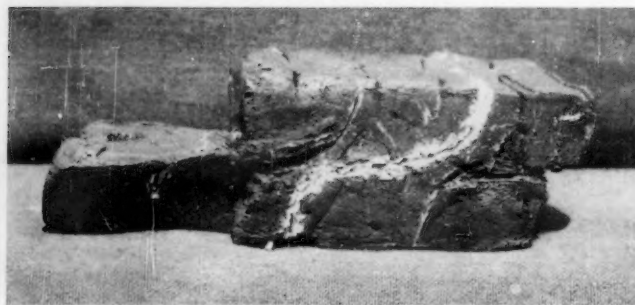


FIG. 10—Lines of Deformation in a Shear Sample.

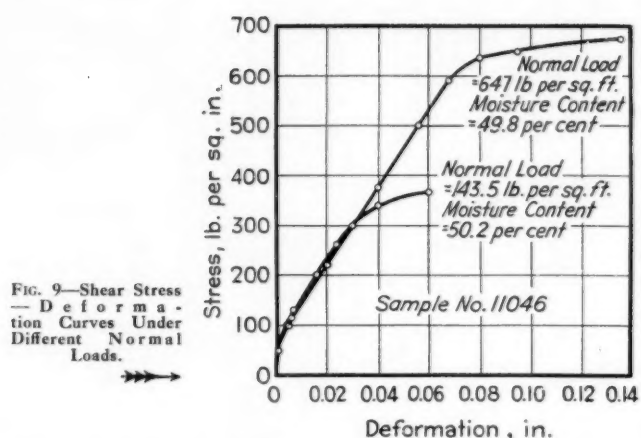


FIG. 9—Shear Stress—Deformation Curves Under Different Normal Loads.

of the method described herein might be subject to some controversy. Nevertheless, the method as a whole is considered by the authors to be very helpful in the treatment of a complex soil property and believed to be correct enough to serve for general purposes of design.

Fig. 10 illustrates the manner in which a plane which was vertical in a sample before test, was distorted after the sample had been sheared to failure. The sample was specially prepared for test by introducing thin planes of white powder normal to the direction of shear load application.

Fig. 11 shows data obtained in the same manner for maximum recorded horizontal deformations of 0.1, 0.2, 0.3, and 0.44 in. in tests of samples 1 in. thick.

In the construction of the stress-strain curves of Fig. 12 from the shear stress - normal pressure relations of Fig. 5,

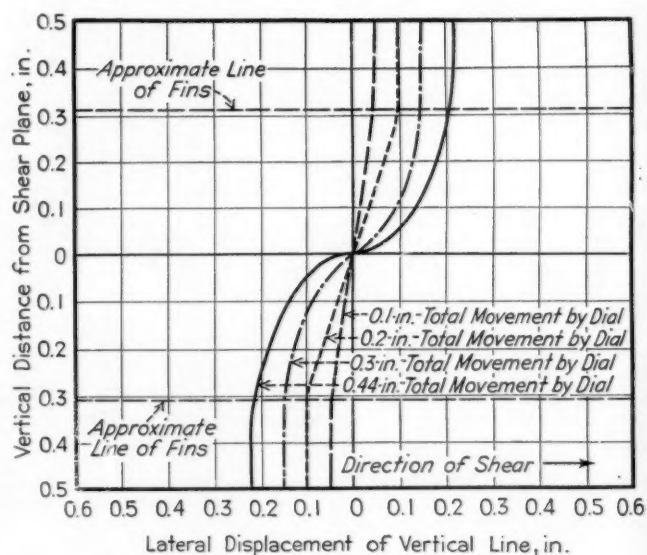


FIG. 11—Horizontal Deformations in a Shear Sample.

the effect of sample thickness was taken into account by expressing the average horizontal deformations as percentages of the vertical thicknesses of the samples between the edges of the fins or grids.

It was further assumed in constructing Fig. 12 that shear stresses as well as the ultimate strengths, developed by deforming the soil at given percentages of the ultimate deformation, are comprised of friction components indicated by the slopes of the stress-deformation relation lines shown in Fig. 5, and cohesion components indicated by these lines at zero normal pressure.

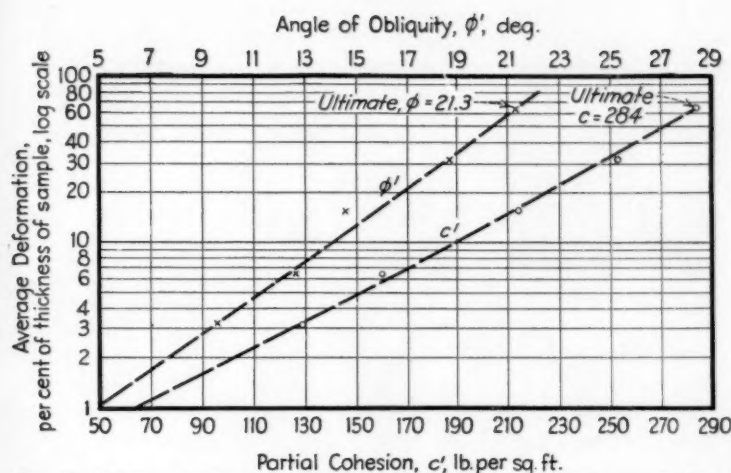


FIG. 12—Relation of Movement, Angle of Obliquity and Partial Cohesion Obtained in Shear Tests.

Investigations made by L. W. Teller and Earl C. Sutherland⁶ in connection with concrete pavement design included observations of the movements of a soil layer formed by digging a groove in the subgrade at the leading edge of a concrete slab 4 ft. square. When a horizontal force was applied to the slab the friction between it and the subgrade caused the soil layer beneath to distort or bend horizontally. As shown in Fig. 17 of the report referred to, the horizontal deformations were largest at the top of the soil layer and gradually diminished at increasing distances below the top.

In the same manner the soil masses may distort or bend for considerable distances on each side of the plane of shear which might ultimately be developed, enough to cause failure of superimposed structures, long before the distortions become large enough to exceed the true or ultimate shear strength of the soil.

The relation of the distortion in the test sample to that which is likely to occur in a fill comprised of similar material is not known. But if, for the purpose of illustrating the use of stress-strain diagrams, it can be assumed that the distortion of the soil in the fill would be equal to that shown by the data of Fig. 12, then its effect would be somewhat as follows:

Let SP , Fig. 13, be the plane upon which complete failure

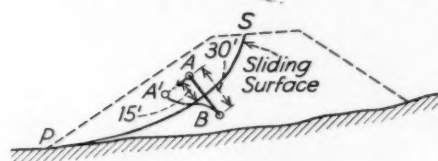


FIG. 13—Movements Due to Distortion.

will ultimately occur; B , the location within the fill at which distortions due to sliding become zero; and A , a point in the area of failure which represents the location of the resultant force productive of sliding. Then the soil at point A would have to be distorted through a distance of 19.5 ft. before failure in true shear would occur, that is, before the true cohesion of about 284 lb. per sq. ft. and the true ϕ of 21.3 deg. would be developed.

If a movement of A equal to 1 per cent of AB or 0.3 ft. were allowable, then $c = 64$ lb. per sq. ft., and $\phi = 4.9$ deg. would apply; if a movement of 10 per cent of AB or 3 ft.

were allowable, values of $c = 187$ lb. per sq. ft. and $\phi = 14$ deg. could be used.

CLOSING COMMENTS

There are many engineers who still regard soil as a material whose structural properties cannot be studied to advantage by laboratory and analytical methods. Many other engineers are reluctant to make use of test data in practice because of their lack of knowledge of soil investigations. It is believed that this condition will be corrected if the practicing engineer is given adequate information concerning the present status of soil mechanics. A frank discussion of the subject should encourage a greater and a more intelligent use of soil information in practice. It should also promote a better understanding between the engineers who are interested in design and construction and those who conduct research.

DISCUSSION

MR. D. M. BURMISTER.¹—The authors of this paper are to be commended on their presentation of this subject. The stress-strain relations are of fundamental importance in analyzing soil behavior. To define those relations accurately and completely is the real task that is ahead of us in soil engineering. They have given us something to shoot at and also have pointed out the enormous influence of the physico-chemical properties of the soil that in a large measure determines its behavior. I think we will find that these same properties carry all the way through soil phenomena, and will be found to be of special importance in shearing phenomena.

MR. F. J. CONVERSE² (by letter).—The paper lists two important considerations which the authors believe should receive the consideration of the Society in connection with the work in soil mechanics. The first of these, dealing with the problem of adsorbed water on soil grains, has been intensively studied in many laboratories in recent years, and the idea well established that most clay particles are surrounded by some sort of an adsorbed film. Exceptions have been noted, for instance, Norton and Hadgdon in "Some Notes on the Nature of Clay," *Journal American Ceramic Society*, Vol. 15, No. 3, March, 1932, list milled quartz as having no such film; while in various other clays the maximum thickness of water film varied from 1×10^{-5} to 33×10^{-5} mm. Such films are of considerable importance on the finer particles of clay, but of less importance on the coarser material.

Figure 1 (b) has apparently been drawn by the authors with the idea of presenting a simple picture of the clay particles surrounded by adsorbed water. This figure is liable to lead to misconceptions (1) because it implies that the particles are all spherical; (2) because of the regular spacing given to the grains; (3) because of the implication that practically all of the water surrounding the grains can be considered as adsorbed; and (4) because the thickness of the adsorbed film is practically equal to the diameter of the particle.

Regarding (1) above, most investigators agree that clay

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²Assistant Professor of Civil Engineering, California Institute of Technology, Pasadena, Calif.

⁶L. W. Teller and Earl C. Sutherland, "The Structural Design of Concrete Pavements," *Public Roads*, Vol. 16, No. 9, November, 1935, p. 169.



particles are more or less flake-like in shape. For instance, Ekblaw and Grim in the Illinois State Geological Survey, *Report No. 42*, p. 13, 1936, state that all clays have a micaceous crystalline habit, and therefore are flake-shaped or flat, but not developed to the same degree in all clay minerals. Regarding (2) above, the regular spacing is of course probably meant to be diagrammatic only. The very graphic illustrations of Terzaghi in his early papers in the *Engineering News-Record* of December 3, 1925, give a much more reasonable conception of the arrangement of spongy or flocculent soil structure, and adequately account for the high percentage of voids in such clays. There is nothing in Terzaghi's picture which does not lend itself to the conception of adsorbed films surrounding the particles. Regarding (3) and (4) above, it appears that to consider practically all of the water surrounding the particles of clay as adsorbed, is stretching that definition too far in the case of clays having a high percentage of water. There seems to be considerable uncertainty on the part of colloidal chemists as to just how thick an adsorbed film may be; and, further, whether such films are always adsorbed or whether they may sometimes be definitely combined with the clay. While the thickness of the adsorbed film may be equal to that of the particle thickness in particles of colloidal size, it certainly cannot be considered so in all cases, especially in clays having predominantly coarse particles rather than colloidal.

Figure 1 (a) is misnamed as "compact" sand sediment. It is a diagrammatic presentation of spherical particles in their loosest state.

The arguments of the authors by which they seek to prove that the older theory of gradual transfer of load from water to soil in a compression test is erroneous, do not seem convincing, unless their Fig. 1 (b) is accepted in its entirety. Under the former conception it is perfectly possible and logical that soil particles, or their adsorbed films, may be in contact even though there is much more water than solid matter in the soil mass.

Concerning item 2 of the authors' thesis: namely, that special studies are urgently needed to determine (a) the significance of data furnished by shear tests, and (b) to determine means of making the data more comprehensive—the writer is in entire accord. The authors have discussed the results of a shear test in which one type of shear test machine was used, and one rate of loading assumed. Other investigators have demonstrated that different results could be obtained with a different type of shear machine, and a different rate of loading. For instance, if the load were applied at a very rapid rate, the deformation within the body of the clay would be small, while if the increments of load were allowed to remain until all movement ceased, the deformations would be very much greater and more uniformly distributed throughout the depth of the sample. The effect of these factors on the shearing strength of clay is being studied by Subcommittee VII of the Society's Committee D-18 on Soils for Engineering Purposes. The effect of the thickness of the sample on the average deformation has not been mentioned by the authors. In this type of shearing machine, as the distance between the applied shear forces is increased, other stresses than those due to pure shear become important, and the deformations are modified. In any practical problem involving deformation, distortions due to all types of stress—tension, compression, and shear—must be

considered. The direct application of the results of the authors' shear test to the deformation of the fill is not warranted, although the idea that it is possible for deformations to cause failure of the structure before the limiting shear stress is reached, is important.

The Highway Department has an excellent opportunity to study the deformations which occur in the adjacent banks of deep cuts, and to correlate these observations with the results of shear and compression tests, and the calculated deformations based on a complete consideration of the stresses involved. It is possible that a simple approximate relationship may be established between the deformations obtained by the shear test and those likely to occur in a highway fill, but considerable experimental evidence will be necessary before the authors' procedure can be accepted.

The criticisms of this paper should not obscure the main point brought out by the authors: namely, that deformations are fully as important as stresses in many problems in earthwork. Figure 5 is also of considerable interest, because it shows graphically the variation in the proportion of friction and cohesion which are mobilized at different stages in the application of load.

MR. W. S. HOUSEL³ (by letter).—Mr. Hogentogler and Mr. Allen, authors of the paper, have called attention to several important problems in soil mechanics with which present-day investigators are engaged. The recognition of the character of the soil-water system in fine-grained soils raises the question as to the applicability of conventional conceptions of internal friction and may indicate the need for readjustment of these fundamental conceptions which are quite generally accepted. In the second place, calling attention to the urgent need for a comprehensive investigation of present shear tests of soil is timely inasmuch as the Society's Committee D-18 is at the present time engaged in an extensive program in which the investigation of shear tests of both cohesive and granular soils is being carried out by some twenty cooperating laboratories. It is hoped that this program, under the chairmanship of Professor Converse, will make it possible to evaluate present test procedure and at the same time throw light upon this important physical property of soils.

On page 15 the authors point out that sand in the inundated state in which it may be assumed that the particles are in contact come to a stable arrangement with porosities of approximately 33 per cent. Compaction of these same materials by vibration check this figure as representing the mechanical arrangement of particles approaching maximum stability. A similar observation in connection with the shrinkage of cohesive soils may be interesting as indicating character of the arrangement of particles in the finer grained soil. In connection with tests to determine the volumetric change of clay soils, the writer's attention has been called by Mr. F. R. Olmstead, Michigan State Highway Department, to the following fact: If the linear relationship between volumetric change and moisture content (see accompanying Fig. 1) is extended to the horizontal axis, representing zero moisture content, the volumetric change equivalent to the shrinkage limit of the soil appears to be relatively constant for most soils, and represents a porosity at the shrinkage limit on the

³Associate Professor of Civil Engineering, University of Michigan; Research Consultant, Michigan State Highway Dept., Ann Arbor, Mich.

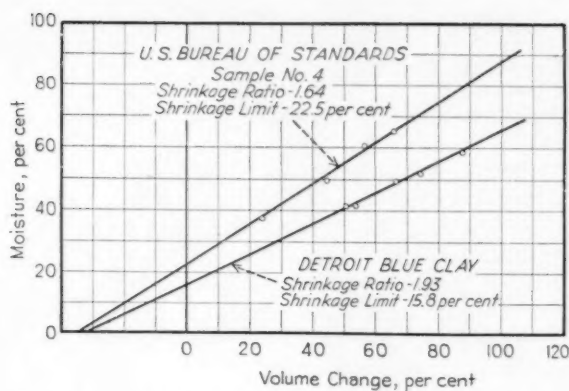


FIG. 1. — Relation Between Volumetric Change and Moisture Content.

order of 30 to 33 per cent. This observation would bear out the contention that when solid particles are actually in contact in either granular or cohesive soils, in a mechanical arrangement approaching maximum internal stability, the porosity is approximately constant. As a corollary to this it may be concluded that for those fine-grained soils, in which the percentage of voids filled with water is substantially greater than this amount, the particles are not in contact and resistance must be that resistance which arises from the molecular forces in the adsorbed moisture films.

In this event it is difficult to see how internal friction as ordinarily conceived can be the controlling factor in the shearing resistance; and in fact, if this is the case and cohesive soils become semi-viscous or plastic solids it would be necessary to apply the fundamental relationships of plastic solids rather than those involved in internal friction. The apparent angles of internal friction, ϕ shown in Figs. 5, 7 and 12 of the paper, would then be simply time effects due to the viscosity of the adsorbed moisture films and the intercepts shown as cohesion represents that shearing stress which must be exceeded before progressive shearing displacement takes place. An investigation of shearing displacement over longer time intervals should then result in smaller and smaller

apparent values of the angle of internal friction approaching zero as the time element became unlimited.

On page 19 the authors state: "soil masses may distort or bend for considerable distances on each side of the plane of shear which might ultimately be developed enough to cause failure of superimposed structures long before the distortions become large enough to exceed the true or ultimate shear strength of the soil." In Fig. 4 the ultimate shear strength of the soil is indicated as the maximum applied load causing failure in a very short time period. It appears to the writer that the authors have failed to recognize that the yield value of the soil, generally defined as the shearing resistance which results in progressive displacement, is very much smaller than the stress which causes rapid failure. In such a rapid shear test performed as described there would necessarily be plastic deformation and flow on all horizontal planes throughout the thickness of the sample and proportional to the distance from the boundary planes in accordance with the laws of viscous flow for all loads in excess of the true yield value. In the general meaning of the term, plastic deformation represents such permanent displacement and is identified with the range of deformation which is progressive and proportional to the time for any load in excess of the yield value. By the same token any load less than the yield value not resulting in progressive deformation would be recognized as elastic deformation and of a very much smaller magnitude.

It appears that failure to recognize the yield value as defined by Nadai and other eminent authorities on plasticity and the test conditions referred to in the previous paragraph, leads to a rather distorted conception of failure under shear as shown in Fig. 13. The magnitude of the displacements discussed in connection with Fig. 13 of 19.5 ft., which is suggested as being possible deformations before the slide actually occurs, is far out of the range of observation in everyday engineering experience.

The authors have called attention to some extremely important considerations in present-day soil mechanics, and this paper may bring out discussion which will serve to clarify existing conceptions of shearing resistance in cohesive soils.

Instrumentation Contest

AN instrumentation contest with a first prize of \$200 in cash is announced by the Industrial Instrument Section of the Scientific Apparatus Makers of America. Twelve prizes in all, totaling \$500, will be awarded by the Apparatus Makers. The contest is open to any engineer or operating man, not employed by an instrument manufacturer. Each contestant is to write about an *unusual* application of a *standard* instrument or control device, telling briefly what conditions or need impelled the application. By instrument or control device is meant any device used for measurement or control in a plant or laboratory, or any accessory used with a device for measurement and control.

The contest closes Nov. 15, 1938, and the judging will be held during the week of Dec. 5. Copies of the contest rules and official entry form can be obtained from the Scientific Apparatus Makers of America, 20 N. Wacker Drive, Room 3014, Chicago, Ill.

Science and Industry Research in Australia

A TRADE note received through the Specialties Division of the Bureau of Foreign and Domestic Commerce, U. S. Department of Commerce, as prepared by G. C. Howard, Trade Commissioner in Sydney, Australia, contains information which may be of interest to many members.

A definite step toward research into the problems of secondary industries in Australia was taken when at the end of June, 1938, a bill was passed by the Federal Parliament appropriating the sum of £250,000 for the purpose of scientific and industrial research in Australia.

A National Standards Reference Laboratory is to be established in Sydney and an Aircraft and Engineering Research Establishment in Melbourne. In addition testing and information services are to be organized to assist industry.

Initially the Standards Laboratory will comprise three main sections—metrology; electrotechnics; and physics, dealing with mass and length electrical units, and heat and light respectively. The main function of the Standards Laboratory will be to establish and maintain national standards and to calibrate substandards used for scientific and industrial purposes.



XX. Long-Time Society Committee Members

Twentieth in the Series of Notes on Long-Time Members

AS A continuation of the series of articles in the ASTM BULLETIN comprising notes on the outstanding activities of long-time A.S.T.M. members, there are presented below outlines of the work of three additional members. In general the men whose activities are described in this series have been affiliated with the Society for 25 years or more and have taken part in committee work for long periods of time. No definite sequence is being followed in these articles.



H. C. Boynton

E. J. Russell

R. W. Crum

R. W. CRUM, Director, Highway Research Board, National Research Council, Washington, D. C., after his graduation from Iowa State College in civil engineering (1907) was employed by the Pennsylvania Railroad Co. Then he was Instructor and Associate Professor, College of Engineering, Iowa State College, serving until 1919. During this time he was also on the staff of the Engineering Experiment Station. There followed a period of service as Engineer of Materials and Tests for the Iowa State Highway Commission. During this time he did considerable to place the construction of concrete roads in Iowa on a sound technical basis. Since 1928 he has been Director of the Highway Research Board, where his work involves all phases of highway engineering, economics, and administration.

Mr. Crum's membership in the Society dates from 1911. He has been especially active in the work of Committee D-4 on Road and Paving Materials, chairman 1928 to 1930, and Committee C-9 on Concrete, chairman 1932 to 1938. In addition to long periods of service on these committees, he has been a member for many years of Committees A-5 on Corrosion of Iron and Steel, C-6 on Drain Tile, and also is a member of Committees E-1 on Methods of Testing and A-1 on Steel. His present term of office on Committee E-9 on Research began in 1934.

He has taken an active part in the work of other societies and is a member of the following: American Society of Civil Engineers, American Concrete Institute, American Public Works Association, and Iowa Engineering Society.

E. J. RUSSELL, Architect, Member of Firm, Mauran, Russell and Crowell, St. Louis, Mo., received his early education in the public schools of Colorado. He began studying architecture early and became a member of the firm of Mauran and Russell in 1900. One of the country's foremost architects, he has designed a great many outstanding buildings and structures in the United States, particularly in the central and southwestern sections.

Mr. Russell has been a member of the Society since 1906. His committee affiliations have been primarily in the field of timber and he has taken an active part in the work of Committee D-7 on Timber, having been a member since 1908.

He has taken part in many civic and related activities in St. Louis, having served as chairman of the St. Louis City Plan Commission, and having headed the Transportation Survey Commission. He was First Vice-President of the Construction League of the United States. Perhaps his outstanding association work has been in connection with the American Institute of Architects. He was vice-president in 1923, also 1930 to 1932, serving as president 1932 to 1935. He is a member of the National Housing Conference, National City Planning Conference, Royal Institute of British Architects, and was decorated Knight First Class, Order of Vasa (Sweden).

H. C. BOYNTON, Chief Metallurgist, John A. Roebling's Sons Co., Trenton, N. J., following his graduation from Plymouth High School entered Harvard University and received his A.B. degree in 1900, magna cum laude; S.M., 1901; and in 1904 was awarded the doctor of science degree. For several years until 1906 he was Instructor in Metallurgy and Metallography as Assistant to Professor Sauveur. Since that time he has been metallurgist with his present company, Chief Metallurgist, 1931 to date. In this position he is in charge of all metallurgical work in the research laboratory of the company.

Like a number of other pioneering scientists in his field, he has taken an active part in various phases of A.S.T.M. work. He first became a member in 1907. His membership on Committee E-4 on Metallography dates from 1910 and from 1924 to 1930 he was chairman. He has been a member of Committee E-8 on Nomenclature and Definitions for many years.

Doctor Boynton also holds membership in the American Institute of Mining and Metallurgical Engineers, British Iron and Steel Institute and the American Society for Metals. He has prepared numerous articles which have been published in the technical and business press and has been active as lecturer before various chapters of the American Society for Metals.

1938 Year Book Mailed

THE 1938 A.S.T.M. Year Book, publication of which has recently been completed, is being mailed to all members of the Society who have requested a copy, a return card having been sent for this purpose in May. Any member who has not requested a copy and who wishes to obtain one should write A.S.T.M. Headquarters immediately. As customary, this edition contains the membership list, detailed personnel of committees, gives the By-laws, Regulations Governing Standing Committees, Society representatives, etc.

It should be pointed out also that there is a section giving general information on the Society and membership application blanks have been bound in the back portion of the book so that members will have these conveniently available.



Recent Developments in European Research on Fatigue of Metals

By Richard P. Seelig¹

EDITOR'S NOTE.—This paper is being published in two sections. The second section dealing with Results of Experimental Research will appear in the December ASTM BULLETIN. The complete list of references appears in this issue.

THIS paper is the result of careful study of the fatigue research as carried out in Europe during the past two or three years. It includes a review of English, German, Austrian, French, Polish, and other publications, information gathered by personal contact with German research men, and results of the author's own experiments carried out abroad.

The survey pertains to various branches of fatigue research, such as theory, testing methods and apparatus, and actual test results. The latter group includes contributions to the problem of factors influencing the fatigue limit, such as, notch-effect, shape-effect, corrosion, method of manufacture, etc.

The conclusion brings a summary of the general trends in modern European fatigue research and an outlook into the future possibilities and aims.

THE purpose of fatigue testing is to subject the materials to stresses which more nearly simulate those in actual application than the stresses exerted by the so-called statical tests. As is well known, the characteristic of this type of testing is to strain the specimen moderately under frequent repetitions.

If a material is submitted to a stress, the value of which oscillates continuously between two limit values, and the absolute amount of which surpasses a definite limit (fatigue limit, endurance limit), the material will break after a certain number of stress cycles. This number depends upon how much this limit has been exceeded.

The fatigue limit is the maximum value of a stress, changing periodically with time which the material theoretically is able to withstand indefinitely.

For practical purposes 1 to 2 million cycles is considered in Europe as adequate for the determination of the fatigue limit of steel. No definite minimum number of stress reversals has been developed for non-ferrous metals. For aluminum the figure 200 million is mentioned in several publications.

These considerations are based on the assumption that there is a definite fatigue limit; in other words, that there is a certain stress under which the material will not fail no matter how often this stress is repeated. This is now generally accepted among European scientists as being the case.

It is inherent in the nature of fatigue of metals that uncontrollable circumstances and details play an important part. The most prominent among them is the surface condition of the member and the microscopical condition of the material.

The first fatigue tests were carried out by the ingenious German railroad engineer, August Woehler. He developed the essential details of the technique of fatigue testing, most

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication, or for the attention of the author. Address all communications to Society Headquarters.

¹ Plant Manager, Powder Metallurgy, Inc., Long Island City, N. Y. Presented at the Forty-first Annual Meeting, Am. Soc. Testing Mats., Atlantic City, N. J., June 27-July 1, 1938.

² A list of references is appended to this paper, see p. 30.

of which are still being applied practically unchanged. His conception of the nature of fatigue was rather hypothetical; however, the question has remained unanswered thus far. A variety of theories have been recently developed in Europe and the first chapter deals with some of them.

The more recent investigations in Europe indicate that the fatigue test according to the Woehler principle, that is, with standard specimens, do not simulate conditions in practice. It is emphasized that formerly such methods were used in testing materials which did not have much in common with the stress conditions of modern machine engineering. The aim is now to ascertain property values from which the quality and usability of a material can be determined.

In recent years it has become more and more evident that the shape of an article has a very definite influence, and that this influence in many instances is even greater than that of the material itself. It is found, therefore, that there is no such thing as strength properties determined by the nature of the material alone; material and shape together determine the strength. Consequently it is necessary to investigate the materials under conditions more nearly conforming to actual requirements.

CHAPTER I—Theories on Fatigue and Fatigue Failures FATIGUE AND CRYSTALLINE STRUCTURE

Czochralsky and Henkel² take as a basic idea for their explanation of the process of fatigue a mutual relationship between the sliding resistance and the tearing resistance of a material. They assume that the same stress may have a different effect in different sections of the material because a multicrystalline structure cannot act as a homogeneous substance.

By extensive research work Gough found that the essential characteristics of deformation and failure are substantially the same, whether the specimen consists of two or three large crystals or a single one. The effect of orientation is probably appreciable; the presence of the intercrystalline boundary to some extent prohibits slip; it also appears to restrict the "damage" caused by slip, and it may influence the rate of propagation of fatigue cracks. But these are merely differences of degree, to be classified as modifying influences. No essential difference in the nature of fatigue failure has been distinguished between single crystals and polycrystalline aggregates.

Considering the fatigue characteristics of a ductile metal it is undeniable that fatigue failure is inseparably associated with failure of elasticity by the process of slip. It is certain that failure is determined almost entirely by the criterion of resolved shear stress, normal stress being apparently only of minor importance. The initial location of failure is always connected with plastic movements along certain crystallographic directions and, in the general case, parallel to certain crystallographic planes. Gough holds, therefore, that fatigue failure must be considered as a consequence of slip; and, if this conclusion is accepted, the subsequent stages of fatigue become comprehensible in the light of observed phenomena.



The result of slip is not a mere relative translation of adjacent parts of the crystalline structure; it rather becomes fragmented into component parts of differing orientation. Gough concludes that fatigue failure does not result from the consequences of slip and strain-hardening on a crystalline structure in general, but only in certain local regions, junctions of crystallites, formed by crystal break-up. At these junctions some lattice bonds will be in a state of severe strain and, as the process of cold-working by repeated stressing is continued, the limiting lattice strain of some of these bonds will be exceeded, producing rupture and the formation of discontinuities in the lattice. When the relative orientation of neighboring crystal fragments exceeds a certain value, the rupture of atomic bonds becomes a cumulative effect with the result that the discontinuities of structure develop through the stage of submicroscopic cracks into that of visible cracks which spread under repeated stress cycles, in the well-known form of the creeping fatigue crack.

With regard to the fatigue failure of *brittle* metals, the available evidence is extremely limited and one hesitates in drawing general conclusions. The consideration of slip is excluded because no plastic deformation occurs. It seems that in many cases fatigue cracks originated due to discontinuities (twins) of structure.

DAMPING CAPACITY

Many attempts have been made to ascertain whether, and how, fatigue may become evident before the first cracks appear. Attempts were made to draw conclusions on the stage of fatigue from an energy value which is based on the number of stress reversals, the stress value, and the deformation. This, however, does not seem to have practical importance.

Damping capacity is the ability of a material to transform part of the energy introduced during oscillation into heat. This capacity, found as energy per volume unit and oscillation (cm.-kg. per cu. cm. and oscillation) is dependent upon the number of cycles and the amplitude. The preparation of the material, its state of cold working, annealing, aging, etc., also have a definite influence.

If a material is stressed between two equal limiting values of contrary direction, the course of stresses forms a cycle if Hooke's law is maintained. The deformation against the stress is represented by a straight line. If the stress is now increased into the field of plastic deformation, less energy is regained after removing the load than has been put in by loading. The difference is used up in plastic deformation, the energy being transformed into internal heat. This heat may be used as a measure of the absorption of energy. Considering again the course of stress against deformation, one gets in this case no longer a straight line but a loop (hysteresis). The area included within the loop is the amount of work transformed into heat. Since this energy consumption dampens free oscillations and makes them die out, this phenomenon is called damping. It is not quite clear as yet why some materials absorb considerable amounts of energy while others do not.

According to Foepl the damping of materials is very important because the behavior of materials under alternating stresses largely depends on it. It renders a plastic in addition to the elastic deformation. This plastic portion of the deformation serves in consequence to dissipate stress

peaks as they occur under purely elastic deformation in flaws, surface injuries, sudden cross-sectional changes, etc. Foepl claims that there is a definite characteristic damping value for each material. It is the one corresponding to the fatigue limit that he calls the "limit damping capacity."

Contrary to this conception, Herold of Austria maintains that the damping capacity is not a material property. He doubts that the damping capacity is of practical importance.

Attempts to establish laws of relation between the damping capacity on one side and tensile strength, yield point and similar values on the other, were not successful. It is difficult to classify materials according to their damping capacity. Lastly, it was not even possible to establish any definite relationship between various compositions of steel (and the corresponding properties) and the damping capacity of these steels.

All this seems to indicate that the damping capacity is a rather dubious chapter in fatigue research. Nevertheless, it must be stated that more and more interest is being attracted by this phenomenon and that positive results may be expected in the near future. There is already a testing machine on the market which records the damping characteristics and which affords very interesting and practical conclusions.

FATIGUE OR NOT FATIGUE?

In the introduction to a paper on new fatigue testing machines, J. S. G. Primrose emphasizes the importance of the fatigue tests by claiming that 90 per cent of engineering failures are due to fatigue in some form or another; the stress involved may be in tension, compression, bending, shearing or torsion, and under complex conditions a combination of any two or more of these.

But in a paper, read to the Manchester Association of Engineers, Primrose states that the term of fatigue has been sadly overworked in explaining the unaccountable failures of the past.

A long time elapsed between Woehler's fatigue tests and the general recognition of the importance of fatigue. Today, however, many failures are being attributed to fatigue, whereas they may be due to simple oversteering. Ulrich has given an interesting proof of this fact by means of his investigations with spline shafts. Cracks in these shafts, which are used extensively in automobiles, start in the corners of the notches. The conclusion was drawn, therefore, that this phenomenon was the well-known notch effect under repeated stress.



Radial cracks in a spline shaft.

Ulrich proves, however, that these radial cracks are being produced by stresses beyond the yield point and occur in the same manner in plain cylindrical shafts. Moreover, he could reproduce the same type of crack with 10 stress reversals.

A new light on the question for the nature of fatigue has been obtained from the experiments of Welter in Poland on the influence of oscillations on the strength of materials. The results are extremely interesting and it seems most appropriate to say a few words about them here. To be sure, these are not fatigue tests. The author submitted wire tension specimens during stressing to oscillations by vibrat-

ing them with a bow of horsehair strings. Oscillations with a frequency of around 3000 cycles per second were applied for an average period of 10 min. It was found that the strength of almost all materials investigated (steel, brass, aluminum, and magnesium alloys) was appreciably decreased by these high-frequency oscillations. The tensile strength dropped about 3.7 to 8.6 per cent and the elongation about 7.5 to 4.7 per cent. (This influence is remarkable in that it holds for oscillations above as well as below the sound range, when one considers the short time of their application.) It would be interesting to submit fatigue specimens to similar oscillations and determine the effect.

FATIGUE FAILURE

Bending: Fatigue failures caused by alternating bending stresses show two zones on their area: the real fatigue crack and the instantaneous crack of the residuent cross-section. The fatigue crack has a dull, velvety surface, whereas the rest crack appears coarser, glossy and crystalline. Glossy spots in the fatigue crack indicate that the adjacent flanks of the crack rubbed and pressed against each other during "breathing" (movement of the cracked piece).

Very often there are concentric zones within the fatigue zone itself. These are stop lines, indicating that the broken part has been stressed intermittently. During the stop period, the stress concentration in the impending crack may be relieved by plastic deformation. Another cause for these "annual rings," as one may call them, are various over stresses that occur during operation and produce different speeds in the progress of the failure. These lines may be reproduced on the testing machine by interrupting the test from time to time.

Beside these general characteristics, other details, mainly at bending failures, give definite information on the stresses causing the fracture. These are the shape of the border line between the two zones and the location and size of the instantaneous crack.

Oschatz calls attention to the fact that if there are stop lines in the crack, they have once been border lines. This phenomenon allows conclusions to be made, for example, on the progress of the failure and it appears as though the speed of the crack penetration increases with the square of the depth of the crack. The absolute value of the progress of a crack depends, of course, on the intensity of the stress.

Some typical configurations of fatigue failures due to bending stresses follow. The two zones of the fractures are distinguished thus:

 Fatigue zone  Residuent zone (instantaneous fracture).

1. *Plane bending* (to and fro in one plane), one or two directions.

(a) *One-way bending.* Stop lines are indicated, showing that the crack starts in circular shape. But as it penetrates the inner particles are subjected to smaller stress since they are closer to the neutral axis, and the lines flatten out.



(b) *One-way bending.* Often a second crack starts in the compression area, probably due to the tensile stresses caused by the elastic forces, restoring the original shape of the bar during the unstressed part of the cycle.



(c) *Two-way bending, highly overstressed.* In this case, the cracks start on both sides simultaneously and proceed with almost equal speed. The consequence is a symmetrical location of the residuent area in the center.



(d) *Two-way bending, little overstressed.* Here, surface conditions and accidental influences play an important part, so as to start the crack at the most convenient spot, whereas at the opposite fiber the crack may begin to form later, depending upon the conditions.



(e) *Two-way bending, Circular V-notch, specimen highly overstressed.* The notch due to the stress concentration near the surface causes a convex appearance in the instantaneous crack.



(f) *Circular round notch, tough material.* The convex characteristics of the instantaneous crack one increases with the sharpness of the notch.



(g) *Circular round notch, brittle material.*



(h) *Bars with transverse holes behave according to the previously developed phenomena. Highly overstressed.*



(i) *Slightly overstressed axle with transverse hole.*



2. *Bending under rotation* (stressed on all fibers.)



(j) *Highly overstressed.* The borderline between the two zones is no longer circular but a cubical parabola.



(k) *Slightly overstressed.*



(l) *A circular notch causes an all-around start of the crack in case of high oversteering, whereas*



(m) *Slight oversteering may again start the crack at the weakest spot. Brittle material.*



(n) *Slightly overstressed, very tough material. Only this kind of material shows no response to the stress concentration by the notch.*

The characteristic forms of fatigue failure of such pieces which are stressed by monoplane or circular bending, (as shown in the above diagrams) do not always occur in compliance with the laws developed. Many deviations occur, having their reasons in the form of adjacent parts (steps or keyways) in heterogeneity of the material (decarburization at the surface, etc.) or in primary inherent stresses in the metal.

Tension and Compression:

The formation of zones in this case of stressing is essentially the same as for the bending fatigue. Since the forces leading to the crack are equal for each cross-sectional element, the speeds of progress are the same in all directions. In consequence, the border line between the two zones in



this case has an approximately circular shape. In contrast to the bending crack, however, the curvature of this border line does not change in passing the center.



A circular notch has also similar influences as in the case of alternating bending. It also causes the zone of the instantaneous crack to be more or less enclosed by the fatigue crack zone.

Torsion:

The appearance of fatigue failures due to alternating torsional stresses is entirely different from the one discussed heretofore. The reason for this is the fact that the forces do not act normal to the area of rupture but rather in that very plane itself as transverse or shearing stresses. This mechanism causes the adjacent flanks in the crack to rub constantly against each other, thus pulverizing some of the material. The detached particles (for example, steel) oxidize easily and are extended from the crack as reddish-brown powder. This phenomenon is called bleeding.

Cylindrical shafts made up from material free of inclusions always show a typical helical torsion break, well known from the crankshaft failures. Bleeding occurs mainly at the beginning because later on the propagation of the crack is largely effected by bending strains.

The Method of Crack Propagation:

This is very important for the judgment of fatigue failures. In its course through the piece the crack follows that curve normal to the stress lines, which starts at the beginning of the crack. By this connection with the field the progress of the crack becomes dependent upon the surface conditions and thereby upon the shape of the piece itself.

Fractures which originate under simultaneous surface corrosion differ from ordinary fatigue failure insofar as they proceed like a rather wide cleavage into the material.

The formation of the crack depends upon the strength of the corroding medium:

A surface-corrosion-fatigue crack starts under strong chemical action and sufficiently high alternating stress, whereas intercrystalline corrosion takes a weak corroding action and a rather high stressing with a passivation of the crystal planes.

CHAPTER II—Testing Devices

ROTATING BENDING

Prot emphasizes that in order to obtain a Woehler-curve for a material with an ordinary revolving bending stress device some 10 to 20 odd specimens are required and one fatigue machine may be tied up for several weeks. In order to reduce these inconveniences the first step taken in the French aeronautic research was to adopt a relatively small specimen, whose size and shape are given in Fig. 1.

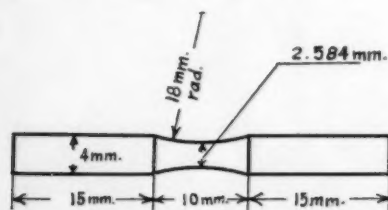


Fig. 1.—Test Specimen for Multiple Spindle Machine.

One of the main advantages of this specimen is that it permits taking it from machine parts chosen at random from a lot; it also permits the production of numerous test specimens at rather low cost and thus makes fatigue testing more economical and reliable.

The second disadvantage mentioned is overcome by Prot's construction of a multiple spindle machine. A single motor drive does not seem to have been successful, because his last model is provided with a motor for each shaft. The motor current is then, as usual, cut off at the moment of failure. A separate counter is provided for each set. The main advantage of assembling this machine, actually an assembly of several independent testing machines, is that it can be conveniently enclosed and it is claimed that these French machines run noiselessly.

The specimens are connected with one cylindrical part to the drive, the opposite one loaded like a cantilever. The specimen is slightly inclined to the horizontal in order to avoid full distortion during rotation.

Another French test specimen of the rotating beam cantilever type is shown in Fig. 2.

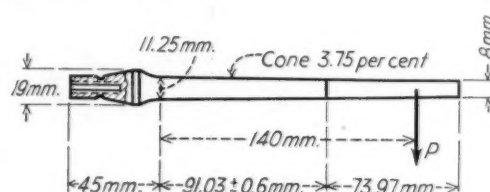


Fig. 2.—Standard Test Specimen of the French Air Ministry.

Note the way that attempt is made to maintain an equal stress all along the length of the specimen and to provide a smooth transition to the part held in the chuck.

Primrose holds that the day of the experimental test piece of diminutive size has passed, that we have learned nearly all it had to tell us, and that today machines are being constructed for the purpose of obtaining the fatigue value of completed articles. Such articles are locomotive axles, complete riveted members, similar welded structures, and even appreciable lengths of large wire ropes.

TORSIONAL FATIGUE TESTING MACHINES

A very useful new form of torsion testing machine for determining the values for large bars has recently been introduced in a form so as accurately to measure the torque, and to apply stresses in either or both directions.

The round test specimen *A* in Fig. 3 which may vary from 5 to 9 1/2 in. in length, is gripped securely in two heads *B* and *C*; the right one is fixed, while the one on the left is rotated about a small angle fixed by setting an eccentric crank mechanism *N* in the graduated flywheel *M*. For static tests and for adjusting the preload and alternating positive loads, there is a total angular travel of 15 deg. between the driving and indicating levers *D* and *E*. For positive and negative loading, however, the angle of travel is only 5 deg. When the test bar begins to fail by deformation, the adjusted preload for the lower limit drops, and under the influence of a weight *O* a wedge *J* slips in under the stop and indicates the permanent deformation on a diagram indicator.

During each test it is possible to check the load limits on the test bar (even when the machine is running) by means of the measuring spring *H*. The twisting of the test bar

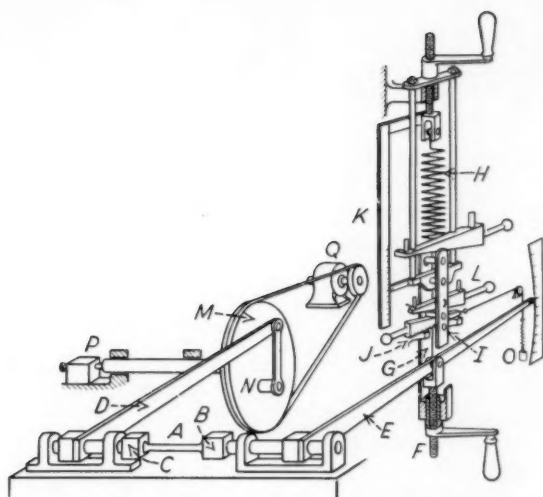


Fig. 3.—Torsional Fatigue Testing Machine.

depresses the indicating lever *E*, the downward movement of which is limited by the adjusting screw *F*. The nut on this screw is attached to the lower end of the stirrup *G* suspended from the measuring spring *H* and is pulled downwards by the pressure of the lever *E*, so that the bolt *I* rests on the lower wedge *J*. If the load on the measuring spring is adjusted so that at the upper limit position of the lever *E* the stop bolt *I* is just out of contact with the wedge *J*, then the tension of the spring is exactly equal to the lower load limit of the test bar expressed in foot-pounds of torque, and read off on the adjustable scale *K*. The upper stop wedge *L* not only prevents any abrupt reaction of the measuring spring when the test specimen breaks, but also serves to block the stirrup if the test bar has to be twisted in both directions.

When the test bar breaks, an electric contact breaker stops the motor *Q* automatically. The rotation counter *P* is operated by the flywheel shaft and reads up to 10 million revolutions. This counter indicates the number of torsional vibrations which the test bar has undergone before fracture.

ALTERNATING TENSION AND COMPRESSION

From the practice of aeronautic construction with its special requirements for utilization of materials up to the limit the demand for a handy alternating tension-compression testing machine arose.

In the German research laboratory for aeronautics a new 5-t (metric) machine of this type has been developed. Figure 4 shows the principle of the machine. The drive is effected mechanically through a crank wheel *A*. By means of a connecting rod *B* the impulse is transmitted to the longer arm of an angle lever *C*. The smaller arm of this angle is connected with a slide *E* through another connecting rod *D*, *E* in turn holding the grip for the specimen. The opposite chuck is mounted on an elastic ring *G* which is fastened to the frame of the machine.

The stress can be adjusted by changing the eccentric on *A*. In order to be able to test pieces of various lengths the thrust bearing *H* has been made adjustable. By means of the spindle between *H* and *G* finer adjustments can be performed and preloads can be applied. The elastic ring measures the load by turning a mirror, which in turn, projects the filament of a light source onto a scale. A coun-

ter registers the number of impulses before fracture occurs. The speed of the machine is 800 r.p.m.

This device can accommodate steel specimens up to 10 mm. and light metal specimens up to 18 mm. in diameter. The length may be as much as 800 mm. Adaption for corrosion fatigue or elevated temperature fatigue is relatively easy.

The fatigue limit found with this machine is somewhat lower than that obtained with the rotating bending type. This checks well with the results of others who have worked on alternating tension-compression.

Electromagnetic Fatigue Tester:

In 1935 a new type of fatigue tester for steel bars which can also be adapted for testing non-magnetic metals was developed by Salford Electrical Instruments, Ltd., in England. The sample bar is supported at its two nodes and vibrated electromagnetically in order to cause it to resonate, a method of testing in which a very great number of cycles of stress may be applied in a relatively short time.

Although this principle is not new some features of the machine are rather interesting:

More than one bar may be vibrated at the same time by providing several units, and the different failure times caused by varying the stress in each can all be determined on the chart of one recorder.

The bar is supported in V-notches and is rubber covered at the points of support to avoid chattering caused by the imperfection of the mechanical contact.

For non-ferrous metals it is necessary to provide steel sleeves over the test bar in the region of the exciting magnets.

The electromagnets for vibrating the bar consist of two pairs of coils on two iron circuits. One pair of these coils is excited by direct current and provides a constant polarizing field. The other pair is excited by alternating current from a gas-filled relay circuit, which in turn forms a variable frequency oscillator. This oscillator can be adjusted so that the electrical frequency corresponds to the natural mechanical frequency of the bar.

In order to trip the circuit when a crack occurs, an auxiliary vibrator is provided. This consists of a length of steel spring, the tension of which can be adjusted to vary the natural frequency and is excited from the same circuit as the main a.c. coils. After the main circuit has been tuned, the auxiliary vibrator is tuned by varying the tension and then detuned slightly by a half-turn backwards of the tension

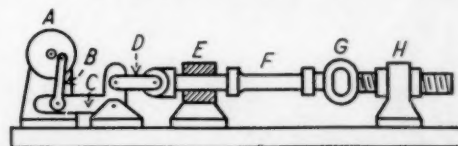


Fig. 4.—Alternating Tension-Compression Testing Machine (Mechanical).

screw, the natural frequency being thereby lowered, so that no appreciable vibration occurs. When a crack appears in the specimen, the natural frequency is reduced, and the auxiliary vibrator comes into action, vibrating with an amplitude sufficient to touch a fixed contact. The unit is thereupon shut down, and the corresponding pen of the recorder is lifted, so that the record indicates the point at which the particular bar has failed.



The standard fatigue tester is designed for 1/2-in. round steel bars of 18-in. length, for which the natural frequency is between 250 and 300 cycles per second. The apparatus may be adapted to other dimensions, to deal with non-uniform loads, and for the application of a fixed bending load or torsion as well as the vibratory stress.

Unfortunately, a sketch of this testing device is not available, so that the author is not able to tell how far the described apparatus deviated from the Haigh-machine, commonly in use in this country and in England. No further information is obtainable on the method of testing non-ferrous metals. It seems possible that attaching an iron sleeve on the specimen may cause a nave effect and thereby interfere with the test results.

Pulsator Fatigue Testing:

The latest European advance in full-size testing may be referred to as the "pulsator." This is not a testing machine in itself, but simply an attachment for any suitable hydraulic testing machine, which applies to the test specimen, whether in tension, compression or bending, a series of rapidly repeated load impulses so that the upper and lower load limits remain constant during the test.

The pulsator has two pistons driven by the same crankshaft, and the oil expelled and retracted by the piston rams produces the variations in pressure in the working cylinder of the testing machine.

The test specimen can be preloaded while the pulsator is running, but no delivery of oil takes place when the two pistons are in opposition. By rotating one of them, the oil displacement can be regulated to bring about the desired stress oscillations between upper and lower limits which are indicated on pressure gages.

In this way it has been found possible to make tension tests on ropes up to 20 ft. in length, to test riveted members and welded structures to destruction and even to fracture complete locomotive axles under repeated bending stresses. In these tests the actual capacity of the testing machine is 100 tons. The speed of the pulsations can be varied from 250 to 700 per minute depending upon the mass of the specimen under stress.

Resonance-actuated Machine:

Figure 5 shows the principle of a fatigue tester for alternating tension and compression which is being built by C. Schenck in Germany. It is a resonance machine actuated by a bending spring. This spring carries additional masses on both ends, one of them being connected with the eccentric exciter. The center of the spring carries the one chuck

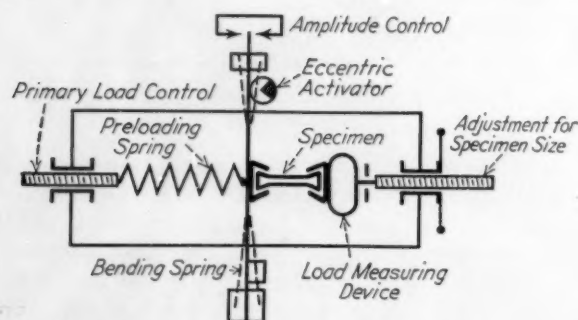


Fig. 5. — Fatigue Tester for Alternating Tension and Compression (Resonance Principle).

and is guided in such a manner that it moves absolutely straight and without any friction. The exciter causes bending oscillations in the bending spring which are symmetrical to the center; the ends of the spring move forward and backwards simultaneously. Thrust pressures of changing size and direction act upon the spring center which is the grip of the specimen. In this manner no additional bending can occur. The oscillation system of the tester operates in the neighborhood of its critical frequency. Therefore, by merely changing the speed of the motor drive the stress can be changed in a simple manner. It is stressed so that by this arrangement the elasticity of the specimen does not interfere with the effect of the system. Merely a certain minimum resilience of the test bar is required.

The helical springs are merely devices to apply additional statical loads, so that all cases of stressing (as explained in the introduction) may be covered.

The measuring device consists of a ring-shape spring with a microscope measuring the deflection. This device is also movable in order to take care of various specimen sizes.

Besides those already mentioned, there are several outstanding advantages inherent in the design of this tension-compression tester. Special gripping attachments allow the testing of plain specimens, specimens with notches, threads, transverse holes, various finishes, machine elements, welded or riveted joints, shapes, etc. The superimposed statical load may be varied in a wide range.

By use of additional equipment it is possible to test the specimens at elevated or low temperatures or with simultaneous corrosion.

Oscillation Bridge:

This is used for testing welded joints on alternating tension and compression. It consists mainly of a framework

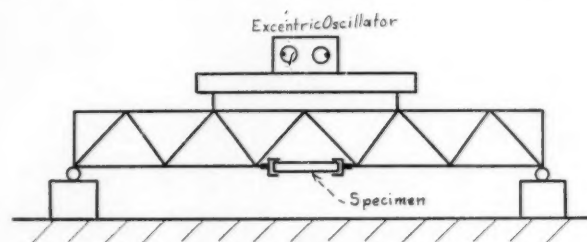


Fig. 6. — Oscillation Bridge.

bridge in whose lower boom the specimen is inserted in the middle instead of one of the members. The vibrations are produced by the oscillator on top of the bridge.

This testing device allows superimposed statical loading of specimens. The dead weight of the oscillators and the bridge itself are sufficient in themselves to provide a considerable statical stress on the specimens. The frequency of the oscillations must be below the critical frequency of the system. It was chosen at about 4 cycles per second for the tests on welded joints.

The dynamical stress can easily be measured by means of the Marten's mirror-deflectometer.

Damping Capacity Tester:

The Maschmenfabrik Augsburg-Nürnberg has developed a new type of fatigue testing machine, which is usable either for torsional or for bending stresses. Its principle is based on the theory that the fatigue limit may be determined

from the change of the damping capacity of a material with the amount and the duration of stressing. The machine is activated electromagnetically and controlled by contacts which, in turn, are operated by the oscillating specimen itself. Curves of the dying-off of the oscillations are recorded by a mirror arrangement on light-sensitive paper.

IMPACT ENDURANCE

It is often possible to replace this test by the much simpler test with approximately sine-shaped stress changes, because in most cases neither the loading speed nor the pause between the impulses has an appreciable influence.

Machines for the impact endurance are working with cams and use gravity, the elasticity of a spring or compressed air, for acceleration of the hammer. The inertia of a mass which is held in its position by a spring under tension is being used for testing bearings and also for testing screw and other connections.

CHAPTER III—Testing and Evaluation Methods

DEFINITIONS

A great deal of the confusion in the field of fatigue testing is due to the fact that there are many variable test conditions. If these are not maintained carefully, the results of two different tests are not comparable. Among other factors, there is a number of possible ways of stressing the specimens, not only concerning the direction (bending, tension-compression, torsion) but also concerning the characteristics of the stress oscillations.

The German Committee for Industrial Standardization has undertaken to standardize some of the terms, symbols and definitions. This will increase the ease of comparing the results of different authors, since it will be possible to make plain the prevailing conditions without long descriptions. This effort is indeed worthy of appreciation and it seems well worth while to discuss the scope of the standard briefly:

Endurance tests are tests in which the stress in the specimen oscillates for a considerable time between two limits, or in which a steady load acts on the specimen for a length of time.

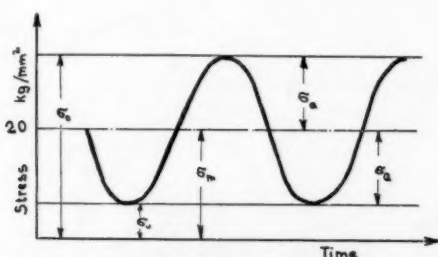


Fig. 7—Symbols for Stresses.

Definitions (Fig. 7)

- (1) σ_0 = peak stress (Oberspannung)
 σ_u = minimum stress (Unterspannung)
 σ_m = mean stress
 σ_a = stress amplitude
 $2 \times \sigma_a$ = fatigue strength (Dauerfestigkeit)
 mean stress and stress amplitude
- (2) N , means number of cycles during test. $N>$, means number of reversals *without* failure. $N=$, means number of reversals *with* failure.
- (3) Strength in contrast to stress is the maximum stress which the test specimen was able to withstand during the endurance test without breaking.

(4) The number of cycles on which the fatigue limit of steel is based is usually 2 million; for non-ferrous metals it is 10 million. When relating test values, the number of cycles on which the fatigue strength is based should be mentioned.

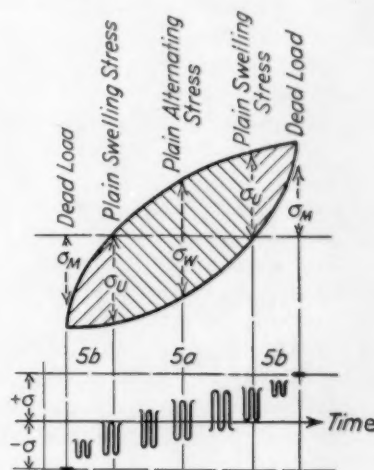


Fig. 8—Fatigue Stress Diagram.

(5) There are two general cases of oscillating stresses:

(a) alternating stresses (Wechselbeanspruchungen), when permanent changing of the stress direction occurs,

(b) swelling stresses (Schwellbeanspruchungen), when only a permanent increasing and decreasing of the stress occurs either in the positive or in the negative range.

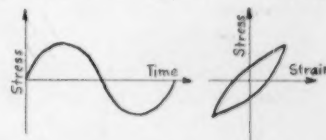
(6) For both groups there is one characteristically special case: the plain alternating stress when the amplitude swings symmetrically to both sides of the zero line; and the plain swelling stress (also origin stress) when the oscillation swings between zero and the maximum value.

Examples of symbols:

- 5a Alternating stress; $\sigma_a = (10 \pm 18)$ kg. per sq. mm.
 (10 = mean stress, 18 = stress amplitude, total stress: 18 kg. per sq. mm.)
- 5b Swelling stress, positive range $\sigma_a = (20 \pm 8)$ kg. per sq. mm.
 (mean stress > stress amplitude, direction does not change)
 negative range $\sigma_a = (-20 \pm 8)$ kg. per sq. mm.
 (mean stress > stress amplitude, direction does not change)
- 6 Plain alternating stress: $\sigma_w = 12$
 Plain swelling stress: $\sigma_a = 14 \pm 14$ kg. per sq. mm.

In the French terminology the following three cases are distinguished:

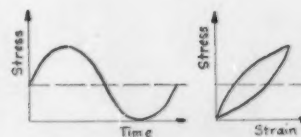
1. Alternating Impulses, (Sollicitations alternées).



The stresses change in alternating directions; the most frequent case is where the values are equal with reversed signs. The mean value is zero.

2. Repeated Impulses (Sollicitations répétées).

The stresses are always in the same direction and change between zero and a fixed value which may be either positive or negative.

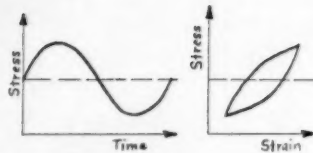


The mean value is $\frac{2}{5}$.



3. Oscillating Impulses (Sollicitations ondulées).

The stresses do not change in direction; they oscillate around a mean value which may be either positive or negative. Concerning the testing method, there is another differentiation:



TESTING UNDER EQUAL DEFORMATION

This method of testing is especially applicable for parts which will be subjected to a forced deformation during service. The testing machines are working in such a way that a fixed deflection of the specimen is maintained throughout the test. Such tests can be very helpful if the investigator wants to study the behavior of the test specimen during the course of the long-time stress, because it is possible to draw conclusions on the change inside the material from the change of the necessary load to bring about the constant dynamic deformation.

There are bending, torsion and tension-compression machines working on this principle.

It is an interesting detail that this kind of machine has to be provided with a recorder or an automatic cut-off switch

to shut off the power when the stress decreases more than 10 per cent. For, if minute cracks form, only a relatively very small load is necessary to bring about the prescribed deformation. Therefore this method takes too much time before the final break occurs.

TESTING UNDER EQUAL STRESS

This method represents the ordinarily applied principle. The stress stays constant, regardless of how the deformation reacts.

Test machines working according to this principle are: Pulsators with hydraulic power supply, which allow testing of all kinds of standard specimens or structural parts. Pulsators are also well suited for ascertaining the time stress which is the time that elapses until a prescribed stress breaks the rod.

The rotating bending machines belong to the same group (Schenck-Moore). They may also be designed in such a manner that a constant momentum is exerted on the specimen. This system of test should not be applied to articles which are not symmetrical of revolution (shafts with flats, etc.).

(EDITOR'S NOTE.—This paper will be concluded in the December issue.)

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Research on Control of Cracking of Asphalt Pavements

By Lloyd F. Rader¹

THE elimination of cracking of asphalt pavements constitutes one of the most important problems confronting the asphalt paving industry. Owing to the importance of the problem, a considerable amount of research on the control of cracking of asphalt pavements has been conducted in the United States during the past few years. Most of the research work has been done on sheet asphalt and asphaltic concrete mixtures.

Because cracking of asphalt pavements is a serious problem, asphalt paving technologists have been asked many questions regarding the effects of various materials and different construction practices upon resistance to cracking. Although many technologists have been able by means of their observations and experiences to answer some of these questions in a general way, there has been a growing appreciation that quantitative test results are necessary in order to decide many of the questions involved.

CAUSES OF CRACKING OF ASPHALT PAVEMENTS

Cracks in asphalt pavements may be due (1) to the characteristics of the asphalt paving mixtures or (2) to structural defects in the pavement. Cracks of the first class are due primarily to failure of the pavements to resist stresses caused by contraction produced by temperature reduction. It is possible to measure the resistance of asphalt paving mixtures to these stresses produced by temperature changes.

Cracks of the second class may be caused by contraction cracks in cement concrete base beneath the asphalt surface course, excessive expansion of rigid base, uneven surface of the base producing a non-uniform density of asphalt surface course, poor foundation support, inadequate drainage of subgrade, poorly made joints in surface course, weakly-braced manhole covers, vibration of street-car rails, etc. A rational method of analysis of this class of cracks appears to be impossible, but the importance of carrying on the paving work in such a manner as to reduce this type of cracking has been pointed out by various authorities. Joints in portland-cement concrete bases to control the formation of cracks in the sheet asphalt surfaces due to expansion and contraction of the base have been constructed by Keily(1)², Director, Rhode Island State Department of Public Works and by Clemmer, Engineer of Materials, Engineer Department, District of Columbia.

RESEARCH ON RESISTANCE TO CRACKING

Research has been largely directed to reducing cracks of the first class which are due to the characteristics of the asphalt paving mixtures. At normal temperatures most asphalt paving mixtures are plastic; without underlying support they deform under the continuous application of rela-

tively small loads. When chilled to low temperature, the behavior of asphalt paving mixtures under load is similar to that of portland-cement concrete. There is a definite load-deflection curve, and significant increases in load are required to produce increased deformations. It seems reasonable to assume that the cracking of asphalt pavements at low temperatures occurs because of excessive tensile stresses due to contraction caused by temperature reduction. The tensile stress produced in chilled asphalt paving mixtures due to temperature reduction may be calculated by the expression:

$$s = ctE$$

where s = tensile stress in pounds per square inch,

c = thermal coefficient of expansion per degree Fahrenheit,

t = total temperature change in degrees Fahrenheit, and

E = modulus of elasticity in pounds per square inch.

The flexure test on beams of compressed asphalt paving mixtures at low temperatures has been developed by Rader(2) to determine modulus of rupture and modulus of elasticity in flexure. Modulus of rupture may be used as a measure of tensile stress and modulus of elasticity in flexure may be used as a measure of stiffness of the mixtures. These values are not the same as tensile stress and modulus of elasticity in tension, but they are suitable physical properties for quantitative measurements and for comparison between mixtures composed of different ingredients and of varying proportions.

The toughness test on briquets of compressed asphalt paving mixtures conducted by means of the Page impact machine (A.S.T.M. Standard Method of Test for Toughness of Rock, D 3-18³) has been employed to determine resistance to impact of traffic.

Correlation between the flexure test at low temperatures and resistance to cracking of sheet asphalt pavements in service has been established by Rader(3) by obtaining modulus of rupture and modulus of elasticity in flexure values at low temperatures on beams sawed from asphalt pavements. This correlation was verified by a subsequent investigation conducted by Raschig and Doyle(4). From the standpoint of reducing cracking in asphalt pavements, it is desirable for asphalt paving mixtures to have high values of the modulus of rupture and low values of the modulus of elasticity. These tests appear to be suitable control tests for use in designing asphalt paving mixtures to resist cracking.

The Highway Research Board of the National Research Council has prepared an "Outline of a Recommended Program for an Investigation of the Cracking of Sheet Asphalt Pavements" in which the flexure test at low temperatures is recommended.

Other investigations of physical properties of asphaltic mixtures relating to the control of cracking include the work done by means of the shear test at low temperatures by Skidmore(5) and the work done by means of the compression test by Roland Vokac(6).

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication, or for the attention of the author. Address all communications to Society Headquarters.

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²The boldface numbers in parentheses refer to the reports and papers appearing in the bibliography appended to this paper.

³1936 Book of A.S.T.M. Standards, Part II, p. 1114.



RELATION OF STABILITY TO CRACKING

The physical properties of asphaltic mixtures at low temperatures tend to supplement the values obtained by means of stability tests at maximum service temperatures. Prevention of displacement of asphalt pavements such as shoving and rutting is recognized to be of great importance and has been accomplished to a large degree by means of stability tests.

Investigators prominent in the development of stability tests include F. S. Besson, Prevost Hubbard, F. C. Field, H. M. Milburn, Walter J. Emmons, B. A. Anderton, Hugh W. Skidmore, M. F. MacNaughton, Henry L. Howe, and M. H. Ulman.

In some cases, unfortunately, the importance of stability has been overemphasized, and mixtures of excessively high stability have been used which have developed poor resistance to cracking at low temperatures. For example, the use of asphalt cement of low normal penetration and the use of mixtures of relatively low asphalt cement content, which generally tend to increase stability, have increased the stiffness and rigidity of the mixtures at low temperatures. Warnings against such practice of designing asphalt paving mixtures to have excessively high stability have been given by Richardson(7), Smith(8), Hubbard(9), Emmons(10) and Skidmore(5).

HARDENING OF ASPHALT INCREASES CRACKING

Hardening of asphalt in paving mixtures has been found to reduce resistance to cracking. Two methods of recovery of asphalt have been commonly used in the United States in determining hardening of asphalts in paving mixtures: (1) the Abson method proposed by Abson(11) and (2) the Dow method proposed by Bussow(12) of the A. W. Dow Co. The penetration and ductility results obtained on recovered asphalts by these two methods do not always agree. Additional research is needed to perfect the methods of extracting and recovering asphalt from paving mixtures. In spite of the difficulties involved, these two methods of recovery have been extensively used to determine hardening of asphalt in paving mixtures. Raschig and Doyle(4) reported as a result of their investigation of asphalt pavements in Ohio that in general the condition of sheet asphalt pavements with respect to cracking is poorest where the values of penetration and ductility of the asphalt recovered by the Dow method are lowest and where the values of modulus of rupture and modulus of elasticity are unfavorable. The Michigan State Highway Department has a specification which limits the allowable decrease in penetration and ductility of asphalts recovered from paving mixtures as compared with original penetration and ductility of the asphalt.

Brannan(13) reported results of studies on hardening of asphalt in asphaltic concrete mixtures showing that from 8 to 32 per cent, or about 25 per cent average, of the original penetration of a 50 to 60 penetration asphalt is lost in placing the pavement on the road. He also has given data indicating that both time and temperature of mixing have a direct effect on the penetration of the asphalt used.

Investigations by Hubbard, Gollomb, and Rader(14) on the effects of overheating asphalt paving mixtures and of prolonging the mixing of the asphalt with aggregate at high temperatures showed that such action tends to harden

the asphalt in a manner similar to oxidation and that this action reduces the resistance to cracking of the pavement. Proper attention to temperatures of asphaltic mixtures at paving plants would contribute to a great extent towards reducing the amount of cracking of asphalt pavements. It may be advisable in certain cases to use asphalt paving cements of initially high penetration so that hardening of the asphalt caused by subjecting mixtures to high temperatures at the paving plant and during transportation to the street will not produce asphalts of too low penetration for proper resistance to cracking.

CONCLUSIONS

The following conclusions summarize the indications and results obtained by research on hot-mix asphalt pavements:

1. An asphalt paving mixture should not be designed to have unnecessarily high resistance to displacement as measured by stability tests without consideration of the resistance to cracking of the mixture, particularly if the mixture is to be laid in localities which have cold winters.
2. Thorough compaction of a sheet asphalt paving mixture is important to develop its maximum tensile strength at low temperatures.
3. Asphalts of high susceptibility to temperature change, as illustrated by cracking coil asphalt, produce mixtures which appear to be least resistant to cracking at low temperatures as indicated in general by their relatively high modulus of elasticity, low modulus of rupture, and low toughness.
4. For the usual paving grades of asphalt, oxidized asphalts in general develop somewhat higher toughness than straight-reduced asphalts which should be advantageous from the standpoint of resistance to impact failure.
5. Other factors being equal, it would appear that those mixtures containing the highest penetration asphalt and the highest percentage of asphalt consistent with necessary stability should prove most resistant to cracking at low temperatures as indicated in general by their relatively low modulus of elasticity, high modulus of rupture, and high toughness.
6. The importance of proper control of plant and street construction operations to insure properly proportioned and well-compacted mixtures of uniform density and to prevent great alterations in characteristics of the asphalt cement, should be emphasized.

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A Discussion Incited by the Report on Pebble Mortars in the 1938 Report of Committee C-1 on Cement¹

By H. J. Gilkey²

THE following excerpts from recent correspondence should, perhaps, constitute the most direct introduction to the discussion which follows them.

Gilkey to P. H. Bates and O. L. Moore, Chairmen of Committee C-1 and of Subcommittee on Plastic Mortars, respectively.

August 26, 1938

Dear Friends:

Enclosed is a copy of a discussion which I am mailing to Mr. Hess. You will note that more or less characteristically this relates to an incident rather than to the project. Nevertheless, I deem that incident sufficiently fundamental to justify the emphasis accorded to it.

Cordially yours,
H. J. Gilkey

Excerpts (Bates to Gilkey, September 1, 1938).

Dear Professor Gilkey:

I had a real thrill when I received yours of the 26th enclosing a copy of a discussion of certain portions of Committee C-1's report to the Society this year.

This is a thrill that came as the result of long waiting. When I first proposed some time ago to Mr. Moore, mortar of the type referred to in C-1's report together with some preliminary data, I was wondering whether I would not be told it must all be wrong, because our "hallowed" cement-water ratio did not hold. But time has passed and you now "bob up" as the first one to point out with any *positiveness* the fact that the mortars in question do unquestionably show the failure of the water-cement ratio as a generalization.

I am hoping that the Society will *not* publish your remarks as a discussion of C-1's report in the *Proceedings*. I am very much against this. On the other hand, I am very much in favor of the Society publishing your remarks in the BULLE-

TIN. After all, your remarks were only incited by the report of C-1. They really have an entirely different theme than C-1's report. Furthermore, if the remarks are published in the BULLETIN, I am sure that the number of readers (may I be pardoned for saying so) would be infinitely *increased* over the number that would read them if published in the *Proceedings*; and then, lastly, your remarks having been read, may lead some few to read C-1's report.

Very truly yours,
P. H. Bates, Chairman,
Committee C-1 on Cement

Gilkey to Bates, September 7, 1938.

Dear Dr. Bates:

Hurray for the thrill, but I fear that you were razzing the professor just a little bit also. I appreciate both your comments and your criticisms and feel that the latter are well taken. I shall alter the manuscript slightly in spots to take account of the points you have raised after I hear from Mr. Hess indicating his preference or decision relative to your suggested disposal of my discussion. I can see the point to your suggestion that this be used in the BULLETIN instead of in the *Proceedings* and will remain neutral on that point. Probably I shall be hearing from Mr. Hess before long.

Sincerely yours,
H. J. Gilkey

THE unusually consistent data from this remarkably satisfying and obviously well-conducted investigation on pebble mortars brings out strikingly some points about portland-cement mixtures which, while not germane to the immediate problem before the subcommittee, are too valuable as evidence, bearing upon fundamental concrete behavior, to be permitted to pass unnoticed. Too often 95 per cent of the meat of a well planned, carefully executed

¹ Preprinted; to appear also in 1938 *Proceedings*.

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series of tests, such as this one, remains permanently unrecognized because it happened to be rump instead of tongue, when tongue was the vogue.

The following quotation starts at the bottom of page 17 (italics are the writer's): "The strengths of the pebble mortars are decidedly higher than the strengths of the C mortar, the average of the pebble mortar strengths being 62 per cent higher than those of the C mortar at one day, 53 per cent at 3 days, 52 per cent at 7 days, 47 per cent at 28 days, and 53.5 per cent for the four periods. *These results are quite unusual since the cement-water ratios used were identical.*" It is stated further that special tests by laboratory No. 4 showed that the differences were not explainable on the basis of Weymouth's grading theory.

These results are "unusual" to the members of the committee only because they were precocious in learning and steadfast in believing that the water-cement ratio *versus* strength relationship was, and is, the alpha and omega of concrete. Having, in common with virtually the entire concrete world, accepted as final this useful but grossly overstated (though oft reiterated) generalization, it is not surprising that such contrary evidence, when finally thrust upon them, should be rated queer.

It so happens that the writer has, for the past 15 years, been afflicted with a morbid curiosity which has led him into many ventures sufficiently academic and impractical to supply him, as a steady diet, with results which were unorthodox to most, unbelievably by many, and of little interest to others. Among these results are some likely to be quite disturbing to the souls of pious W/C adherents. The representative data of the accompanying Table I are not in all respects parallel to those secured by the committee, but they should serve as a basis for demonstrating the reasonableness of the committee's findings.

The three subcommittee mixtures may be tabulated as follows:

| | BATES MIX. | PEARSON MIX. | C 109 MIX. |
|---|------------------|------------------|-------------------|
| Cement, g. | 450 | 375 | 470 |
| Fine aggregate (0-No. 20) | 900 ^a | 835 ^b | 1300 ^c |
| Coarse aggregate (1/2 in.-No. 4) | 1350 | 1250 | 0 |
| Proportions by weight | 1:2:3 | 1:2.2:3.34 | 1:2.77:0 |
| W/C (water-cement ratio) by volume | 0.80 | 0.80 | 0.80 |

^a Consists of 790 g. of standard Ottawa sand (Nos. 20-30) and 110 g. of potters flint which is even finer than the cement. Fineness modulus = 2.62.

^b Consists of 520 g. of standard Ottawa and 315 g. of Ottawa banding sand. Fineness modulus = 2.07.

^c All graded Ottawa: 95 per cent + 100; 72 per cent + 50; 5 per cent + 30, and none retained on No. 16 sieve. Fineness modulus = 1.72. (See *Proceedings*, Am. Soc. Testing Mats., Part I, p. 323 (1934).)

The more detailed grading setup is given on page 16 of the preprint, the arrangement here being purposely simplified to approximate the three general classifications, namely: cement, fine aggregate and coarse aggregate. Obviously the very finely ground potters flint of the Bates mix is, weight for weight, much more of a diluent than is the relatively much coarser banding sand of the Pearson mix (even though the banding sand is very fine as a sand). The graded Ottawa of the C 109 mixture is also a fine-sand grading, but again in no sense comparable to the potters flint of the Bates mixture.

Obviously the two pebble mixtures are rather rich minia-ture concretes which are being compared with C 109, a lean, fine-sand mortar. In comparison with the flint of the Bates mix and the fine banding sand of the Pearson mix, the standard sand (Nos. 20-30) functions essentially as coarse aggregate, since the fine particles are the important ones in diluting the cement (leaning up the mix). The sand of

C 109 is nearly all fine and practically none of it, by comparison, resembles coarse aggregate. Thus the 1:2.77 mortar of C 109 is really much leaner in comparison with the mortars of the other two mixtures than the nominal 1:2 and 1:2.2 would seem to indicate.

The important effect of the sand-cement ratio upon strength is apparent for even the rather coarse sand used in the mixtures of Table I (see item 3 of summary following Table I). The heavy charge of relatively fine sand greatly dilutes the cement of the C 109 mixture and may well be a primary reason for the large reduction in its strength as compared with the pebble mixtures. While the pebble mixtures are probably weaker than they would be without the pebbles, the small sized aggregate (No. 43/8) probably reduces strength much less than would an equal weight of larger particles.¹

The strengths of the mixtures in Table I are in sequence with their cement factors, whereas the cement factor for mixture C 109 is almost exactly twice that for the much stronger pebble mixtures. This apparent lack of concordance is only due to the fact that the Table I sequence includes no comparisons of concretes with really lean mortars. A 1:3 1/2 or 1:4 mortar would probably have been weaker than a 1:5 or 1:6 concrete.

Obviously, the tests of Table I differ from those of the paper in so many important respects, especially as regards the relative amounts and gradings of the aggregates, that quantitative comparisons are not in order. Qualitatively they show, however, exactly what the committee's tests show: that with variable gradings and amounts of aggregate there may be great strength variations (all within the water-cement ratio law, so called).

In discussing the paper by C. E. G. Weymouth, "A Study of Fine Aggregate in Freshly Mixed Mortar and Concrete," presented at the 1938 A.S.T.M. Annual Meeting, the writer has alluded by specific reference to other representative test results which indicate wide variations within the water-cement ratio (and also the voids-cement ratio) law. Few, if any, of these are explainable on the basis of poor aggregates, unworkable mixtures, or faulty gradings. This paper adds to that growing list another excellent illustrative case.

Pearson's mixture with a cement-aggregate ratio of 1:5.54 has a 53 per cent greater strength than mixture C 109 with exactly twice the cement factor. Both mixtures were thoroughly workable; the aggregates were sound, strong, well shaped, non-absorbent, and inert; the thorough checking by different laboratories, the use of several cements, and the tests at different ages combine to give these results a rare degree of authenticity and significance.

The eagerness with which the concrete world has seized upon sweeping generalizations and its apparent reluctance to admit even the possibility of important limitations has, for some years, been a matter of genuine concern to an insignifi-

¹ Others of the writer's test results appear to indicate that at constant water-cement and aggregate-cement ratios, the strength varies directly with the surface modulus, or inversely with fineness modulus of the aggregate. Within the range of workable mixtures, this increase of strength with decrease in size of aggregate appears to hold true for both the coarse and fine aggregates. Even though the mixture is perhaps being strengthened as particles become smaller, it is perhaps being weakened by the increasing diluting effect of the increasing numbers of smaller particles, upon the limited amount of paste. If these suspected opposing trends are present, it is evident that for any given aggregate-cement ratio the trend will be reversed when a degree of dilution is reached such that the weakening from dilution more than offsets the amount of gain from smaller particle size.

TABLE I

| Mixture by weight | Coarse Aggregate Size | W/C (Water- Cement Ratio), net | Slump, in. | Compressive strength, lb. per sq. in. | | | | | | | Average per cent |
|-------------------------|-----------------------------|--|---------------|---------------------------------------|---------------|---------------|---------------|--|---------------|---------------|---------------------|
| | | | | Standard Cured | | | | Variable Curing ^a , Age, 1.5 year | | | |
| | | | | 7 days | 28 days | 3 months | 1.5 year | SD | AD | AW | |
| 1 : 2 : 0 | | 0.86 | 11.0 | 2250 (100) | 3060 (100) | 3900 (100) | 5130 (100) | 6170 (100) | 3030 (100) | 2020 (100) | (100) |
| 1 : 2 : 3 | 1—1½ | 0.86 | 7.6 | 1320 (59) | 1980 (65) | 2520 (65) | 3160 (62) | 3460 (56) | 1920 (64) | 1600 (79) | (64) |
| 1 : 2 : 3 | ¼—1½ | 0.86 | 7.8 | 1650 (73) | 2400 (78) | 3170 (82) | 3860 (75) | 4160 (68) | 2170 (72) | 1510 (75) | (75) |
| 1 : 3 : 0 | | 0.86 | 1.9 | 1780 (79) | 2680 (88) | 3440 (88) | 3740 (73) | 4350 (71) | 2510 (83) | 1890 (94) | (82) |
| 1 : 3 : 4½ | 1—1½ | 0.86 | 0.0 | 1270 (56) | 2060 (67) | 2440 (63) | 2380 (46) | 3160 (51) | 1850 (61) | 1380 (68) | (59) |

Fine aggregate was a washed natural sand and coarse aggregate was crushed quartzite. All specimens, 6 by 12 in. cylinders.

^aSD = Standard cured for about 13 months and exposed to dry laboratory air for about 5 months prior to testing dry. One month air exposure should have produced same results.

AD = No moist storage. In the dry air of the laboratory after removal from mold at age of 1 day.

AW = Same as above but saturated by 24-hr. immersion just prior to test.

Some of the indications of Table I may be summarized as follows:

1. The 1:2:3 concretes have 64 and 75 per cent of the strengths of their 1:2:0 mortar.
2. The 1:3:4½ concrete has 72 per cent of the strength of its 1:3:0 mortar.

3. The 1:3:0 mortar has but 82 per cent of the strength of the 1:2:0 mortar, and is only slightly stronger than the 1:5 concretes.

4. At constant water-cement ratio, strength is reduced as the aggregate ratio is increased, but the reduction is more pronounced for increases in sand ratio than in coarse aggregate ratio, although the effect of changes in neither is negligible.

5. Here the graded coarse aggregate (¼-1½) produces stronger concrete than does the one-size (1-1½) coarse aggregate. There is nothing in these data to indicate whether the difference is due to the grading or to the difference in the average size of particle. Other tests show that small sized particles reduce strengths less than an equal weight of larger ones.

6. Strength ratios are reasonably constant for mixture comparisons at different ages, curings, and test conditions.

cant minority who feel that such a blind faith has led to unwarranted assumptions, hazardous practices, and, worse yet, has blocked fundamental progress with warped concepts. One has only to scan the data of Table I to recognize as major fallacies such devices as:

1. Assuming that the strength of large-aggregate concrete will be the same as that secured from a wet-screened sample of its small-aggregate constituents.

2. Assuming that the strength of a sample will be unaltered by the addition of either fine or coarse aggregate for thickening up a fluid mixture.

Such are illustrative of hazardous practices that are current and which have the backing of many of the foremost authorities in the field of concrete.

Until we recognize and concede that some of the leading "generalizations" regarding plain concrete are really "specializations," we will continue to explain as simply queer or "unusual" evidence not in agreement with our chosen beliefs. In the meantime, some of the most basic and interesting problems of plain concrete will remain unsolved simply because we refuse to admit their existence.

The committee is to be congratulated, not only for its excellent piece of work in the field of plastic mortars, but also for the conclusive, striking and unimpeachable evidence of extreme variations within so-called fundamental laws of concrete proportioning. This highly significant, though inadvertently secured, by-product of the investigation may prove ultimately to have been its larger contribution.

What Causes Gray Hair?

THE September, 1938, issue of the Inter-Society Color Council News Letter No. 21, in its section on "The Colorquerry and Visionnaire" asks the question, "What Causes Dark Hair to Turn Gray and White?" and gives the answer. This scientific explanation may be of interest to some few of our members who have been perplexed by this phenomenon.

"There is a popular belief, we are tempted to say a superstition, that gray hair is caused by worry. We shall not test the hypothesis for lack of reliable objective measures of worry, also because of other lacks. We are rather inclined to credit the explanation which relates the whiteness of aging hair to the whiteness of young Easter lilies and of fresh snow. These all, and some artificial substances, as

enamels, are mixtures of optically unlike components. White hair has air bubbles replacing dark pigment and dispersed in the hair protein substance; lily petals have a similar dispersion, and snow also has air enmeshed in its crystals. Enamels have one solid dispersed in another; there are 'frits,' as fluorides, of low refractive index, and 'opacifiers,' as tin oxide, of very high refractive index, the glassy medium being intermediate. Whites are also obtained in clouds (water dispersed in air) and foams (air dispersed in liquids).

"When light penetrates a mixture of finely divided materials of different refractive index, it is diffusely reflected; and the greater the relative refraction the sooner will the light be returned to the air and the greater the reflection. Since a larger difference in two refractive indices results in fewer internal reflections, there is less absorption and more reflection, and the result is a 'whiter' medium.

"Of course gray hair is hair which has reached only senescence, not senility. If you think this explanation is no good, we'll not worry; our hair might turn gray. Or would it?"



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No. 94

October, 1938

Cooperation in Research

ONE very important factor in promulgating satisfactory specifications for materials is cooperation—in the case of A.S.T.M. standardization work the cooperation of consumer, producer and general interest in reaching mutually satisfactory requirements which can govern the buying and selling of widely used materials.

The need of a close union between research and standardization is well recognized, for without accurate knowledge of the essential properties of a material and adequate methods of determining these properties, a standard giving specification requirements for quality certainly cannot be satisfactory. Often a standard must wait until research finds the answer to questions which have an important bearing on the final decision.

It is significant that in the Society's programs of research and standardization the same men are frequently active in both phases. They may first be developing needed data and then applying that knowledge in the writing of specifications. Recently, the specifications of the ideal research man were proposed by Mr. Ross Gunn, Technical Adviser of the U. S. Naval Research Laboratory. After indicating that he should be well grounded in the fundamentals of physics, mathematics, etc., it was pointed out that

"He should be especially keen in estimating situations and reaching sound decisions. His judgment and perspective should be such that he can give his talents systematic direction. He should be an original thinker and have original ideas. He should be exceptional in his ability to plan, think, and do things without being told.

"He should have the courage of his convictions, yet must not be blinded by them. He should constantly seek the truth. *He should be especially successful in working harmoniously with others toward a common end.*" (Italics ours.)

As in the case of standardization, cooperation is essential in promoting knowledge of materials and it is the close cooperation between the members of the large number of Society committees sponsoring research programs which enables Committee E-9 on Research each year to record important progress, when it reviews the status of A.S.T.M. research. Again this year a number of new research projects are listed, see page 1, bringing the total number of A.S.T.M. projects to above 140.

Realignment of Society's Publications Being Studied

IN VIEW of the very rapid rate at which the specifications and tests of the Society are increasing in number and correspondingly of the pages in the volumes in which they appear, some thought will need to be given shortly to a modification of the Society's publication setup. At present the Book of Standards is issued triennially in two parts, Part I on Metals and Part II on Non-Metallic Materials. The new and revised tentative standards approved each year appear in Part I of the *Proceedings* for that year. Further there is issued annually a compilation of *all* the tentative standards. This Book of Tentative Standards, however, is sent only to those members who purchase it. Supplements to the Book of Standards are issued in the years between the appearance of the Book of Standards, which Supplements contain the standards adopted or revised in the respective years. These Supplements are sent without charge to members and purchasers of the Book of Standards. Tentative revisions of standards are published in Part I of the *Proceedings* and in the Book of Tentative Standards.

Committee E-6 on Papers and Publications, faced with the question as to what further division should be made in the Book of Standards when because of its size it can no longer be issued in the present two volumes, believes that Part II of the Book of Standards should be split so as to make a separate volume of the "C" standards and certain closely allied standards from the "D" group, leaving the remaining standards to comprise Part III of the Book of Standards. In recent years the Book of Tentative Standards has grown to rather unwieldy proportions, so that this year it will comprise some 1900 pages. Obviously some other provision will need to be made with respect to this publication.

Quite aside from these considerations, however, it would appear to be a convenience to have the tentative standards in a given field appear in the same volume with the corresponding standards. The point has been made, for example, that under our present scheme of publication it is frequently quite inconvenient to locate various standards of interest, particularly when it is necessary to refer back and forth from the *Proceedings* to the Book of Standards in order to locate various supplementary standards that may be referred to. A consolidation and rearrangement along the following lines is accordingly under consideration:

Every three years issue the *standards and tentative standards collectively* in three parts:

- Part I on Metals,
- Part II on Non-Metallic Constructional Materials,
- Part III on Miscellaneous Non-Metallic Materials.

In the intervening years a Supplement to each part would be issued which would contain the newly adopted standards, the new and revised tentative standards, and tentative revisions of standards. The new and revised tentative standards would no longer appear in Part I of the *Proceedings*.

Any realignment such as this will entail certain readjustments in respect to the published material furnished members, but first of all the merits of the proposal will need to be determined. Comments on the proposed realignment will be welcomed.



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Secretary Visits Coast Committees

DURING September the Secretary-Treasurer visited the district committees in Northern and Southern California, spending September 13 to 17 in San Francisco with the former and September 18 to 21 in Los Angeles with the latter. The primary purpose was to discuss various administrative and related questions with the district committees and to plan for continued activity on the Coast in the interest of the Society and its far-western members. This purpose was fully achieved despite the limited time available, thanks to the splendid cooperation of the officers and members of the two committees. Of equal importance were the personal interviews and conferences with many members, giving the Secretary opportunity to describe and explain technical phases of A.S.T.M. work of special interest to members and to receive many valuable comments and suggestions respecting extension of A.S.T.M. influence and activity on the Pacific Coast. There was much interest shown in bringing about greater participation of Pacific Coast industries in the research and standardization work of the Society and in promoting greater local A.S.T.M. activity.

The Secretary spoke at two well-attended meetings in San Francisco and Los Angeles described elsewhere in this BULLETIN. In addition he addressed a joint dinner meeting of the Northern California Chapters of the Institute of Architects, Structural Engineers Association and Associated General Contractors held in San Francisco on Friday evening, September 16.

MEETING IN ST. LOUIS

On his way home from the Coast, Mr. Warwick attended a meeting of some 35 members of the Society in the St. Louis region held at the University Club in St. Louis on September 27. This meeting, under the chairmanship of Past-President Hermann von Schrenk, unanimously requested the Executive Committee of the Society to authorize the organization of a St. Louis District Committee in order that the interests of the Society may be more effectively promoted in this important industrial region of the country. The Executive Committee will act upon this request at its October meeting.

Action on 1938 Ballot Favorable

THE 1938 letter ballot on recommendations affecting A.S.T.M. standards was canvassed on Sept. 1 and showed that all items listed on the ballot were adopted. Thus 32 tentative specifications and tests have been advanced to standard and revisions have been adopted in 33 existing standards.

The canvass showed that 575 legal ballots had been cast. While the itemized returns will not be published, any member who desires a record of the vote on any item can obtain this from Society Headquarters.

All of the new and revised standards, with the exception of eight in which the revisions were of such a minor nature that they could be appropriately given on stickers, appear in the 1938 Supplement to the Book of A.S.T.M. Standards which is being distributed to each member of the Society and to the purchasers of either part of the Book of Standards. There were also transmitted with the Supplement stickers, which can be placed in the 1936 Book of Standards and the 1937 Supplement, indicating the revised or discontinued standards. It is important that these stickers be used to bring the standards volumes up to date.

Advantages from Standards

NUMEROUS articles have been written on the significance of standards and the advantages to be derived by using them—from the standpoints of both the consumer and the producer. As one example of such a discussion, and an interesting one, too, we cite the Symposium on the Economic Significance of Specifications for Materials,¹ held in 1931 under the joint auspices of the Western Society of Engineers and the A.S.T.M. Many other pertinent items have been recorded on this subject.

There has just been received a Second Annual Report for the year ending March, 1938, from the New Zealand Standards Institute, Department of Scientific and Industrial Research. In this report is included a list of the advantages from the development of standards. This list from the other side of the world may be of interest to many A.S.T.M. members. The development of standards:

- (1) Defines the materials and processes which render production most efficient and economic:
- (2) Effects economy—
 - (a) By concentrating purchases of the most suitable and efficient material;
 - (b) By ensuring the successful development and application of technological advances:
- (3) Eliminates superfluous types, sizes, and designs, thus ensuring interchangeability of parts with consequent reduction in maintenance charges and general economies in production and distribution costs:
- (4) Eliminates danger hazards by means of the most competent selection of material or equipment on a basis of its pre-defined strength, quality, performance, capacity, and conditions of its use:
- (5) Affords convenience and efficiency through the better facilities and service provided by specially selected materials and equipment:
- (6) Aids general acquaintance with the use of equipment, and renders processes more automatic because of greater uniformity, the advantage of this being particularly expressed in certain specialized spheres and in the transfer of operatives from unit to unit:
- (7) Facilitates the ordering of supplies on a basis of national specifications in place of a multitude of individual specifications, the preparation of which is costly, while their use leads to misunderstanding and conflict. It also places trade on a basis that is equitable and intelligible as between suppliers and between suppliers and purchasers:
- (8) Places on goods a registered quality distinction ascertained by independent experts, and makes this available in a form that equips the average purchaser with a substantial degree of the discrimination of expert buyers:
- (9) Promotes and establishes public confidence in reliable advertising, labelling, or other description of goods, which excludes superficial and confusing elements because it is based upon intrinsic merit defined by National Standards of quality and utility by which commodities, materials, and equipment may be made, tested, and sold.

Standards therefore benefit—

- (a) *The Manufacturer*, by decreased production- and selling-costs, smaller inventories, faster turnover, and consequently increased returns:
- (b) *The Distributor*, by the reduction of inventories to the lines that sell well, thus securing speedier turnover with lower overhead charges:
- (c) *The Ultimate Consumer*, by lower prices, general raising of quality of products, more and/or better goods at a given price.

¹ *Proceedings, Am. Soc. Testing Mats., Vol. 31, Part II, p. 955, 1931.* (Reprints of this are available and will be sent without charge to members and others who would find them of service.)



Microchemical Examination — Subject of Pittsburgh Meeting in November

FINAL arrangements for the meeting to be sponsored by the A.S.T.M. Pittsburgh District Committee, a preliminary announcement of which appeared in the August BULLETIN, have been practically consummated. The meeting is to be held at 8 o'clock on Monday evening, November 14, in the auditorium of the Mellon Institute of Industrial Research, Pittsburgh. Three papers on the general topic, "Examination of Materials by Microchemical Methods," will be presented at this meeting.

Dr. Walter R. Kirner, of the Coal Research Laboratory, Carnegie Institute of Technology, will speak on "Organic Microanalysis." After a brief history of quantitative organic microanalysis, Doctor Kirner will describe methods for the microdetermination of elements and groups, the microdetermination of physical constants, the purification of minute amounts of organic material, and sampling industrial materials for microanalysis. The many advantages of micro-methods for industrial work will be illustrated by actual experiences of numerous laboratories now using these methods for routine purposes. The apparatus used for many of these processes will be exhibited.

The second paper, "Chemical Spot Tests," will be given by Dr. Gordon H. Stillson of the Gulf Research & Development Co. The identification of a drop, crystal, fragment, or trace of an organic or inorganic material will be described and illustrated. The qualitative analysis of metal objects without defacing the surface of the metal will be discussed. Some of the apparatus used in spot-testing will be exhibited and demonstrated. Numerous applications to industrial problems and to standard A.S.T.M. methods will be suggested and discussed.

The third paper of the group, "Microscopy in Industrial Research and Control Work," will be presented by Dr. E. B. Ashcraft of the Westinghouse Research Laboratories. Doctor Ashcraft will give a brief description of the various types of microscopes and accessories, and their uses. The determination of the optical properties of materials will be taken up in detail. The application of microscopy to various fields of quantitative and qualitative analysis will be illustrated by examples from the work of the author as well as from the technical literature. The types of problems which are being attacked through the use of microscopy will be surveyed.

All members of the Society and others concerned with the subject being discussed or interested in the field of materials are cordially invited to attend this meeting.

Meeting of Southern California Members

ABOUT 130 members and guests were present at a dinner meeting held on Tuesday evening, September 20, at the Athenaeum of the California Institute of Technology, Pasadena, under the sponsorship of the Southern California District Committee. The Secretary-Treasurer was present and spoke on a number of phases of the Society's work, with particular reference to the extension of that work into new fields in recent years. In the unavoidable absence of Garner A. Beckett, Riverside Cement Co., chairman of the District Committee, the meeting was presided over by the secretary, E. O. Slater, Smith-Emery Co.

The technical part of the meeting centered around airplane materials testing, the address being made by Tom A.

Triplett, Senior Partner, Triplett and Barton, on the subject "Modern Aircraft Material Testing." Mr. Triplett discussed the advances in X-ray inspection of materials, and presented a series of studies showing a remarkable correlation between estimated physical properties based on the density of X-ray photographs and actual tests of material in tension, impact, and fatigue. It is planned to publish Mr. Triplett's paper in a subsequent issue of the ASTM BULLETIN.

The evening was rounded out by a tour of the structural testing laboratories of the Guggenheim Laboratory of Aeronautics; the pump laboratory in which models of the pumps for the Grand Coulee Dam are being tested; the metallurgical laboratories; and the grinding shop in which the mirror of the 200-in. telescope is being polished. Arrangements for the meeting and inspection tour were made by Prof. F. J. Converse, a member of the District Committee.

Philadelphia Meeting on "Fundamental Research in Industry"

AS THIS BULLETIN is being prepared for the mails, there is in progress a meeting in Philadelphia sponsored by the District Committee at which Dr. L. W. Chubb, Director of Research, Westinghouse Electric and Manufacturing Co., is the principal speaker, on the subject "Fundamental Research in Industry." This meeting was postponed from October 10 to October 17. All members in the Philadelphia area and members of many other local societies have been invited. An account of the meeting will appear in the next BULLETIN.

District Meeting in New York, November 10

THE New York District Committee is planning a meeting on the night of November 10 at the Hotel New Yorker. Committees D-9 on Electrical Insulating Materials and D-20 on Plastics are holding a series of meetings on November 9, 10, and 11, and consequently the district meeting will afford an opportunity to the members of these committees to attend. While a speaker for the meeting has not been announced, full information will be sent to all of the members in the New York District.

Meeting of Northern California Members

A DINNER meeting of Society members in Northern California and their guests was held Tuesday evening, September 13, in the Engineers' Club of San Francisco in honor of the Secretary-Treasurer's visit to the Pacific Coast. The meeting was held under the auspices of the Northern California District Committee, of which F. M. Harris, Pacific Gas and Electric Co., is chairman and Theo. P. Dresser, Jr., Abbot A. Hanks, Inc., is secretary. Mr. Harris presided and introduced at the dinner officers or other representatives from local chapters or sections of sixteen other technical societies and associations interested in engineering materials. There were about 115 members and guests present.

As guest speaker of the evening, the Secretary-Treasurer discussed the work of the Society, past, present and prospective, mentioning some of the newer fields into which the work has expanded and referring to the relationships between the A.S.T.M. and other engineering societies as well as pro-



ducing and consuming industries and their industrial associations. In consideration of the non-members present who were not acquainted with Society procedure, he gave an informative description of the committee organization and the sequence of steps in the preparation and adoption of a standard.

Informal discussion following the address developed several interesting ideas respecting effective application of Society activities and functions to local problems in the testing and specification of materials. The District Committee believes that the meeting will undoubtedly result in a greater appreciation of the Society's work in its many ramifications and still wider and more effective use of its standards.

British Meeting on Non-Destructive Testing— American Paper to Be Presented

AT THE invitation of the British Joint Committee on Materials and Their Testing, the Society has arranged for the presentation of a paper on "Non-Destructive Testing in the United States of America" to be presented at a meeting being held on November 25 in London under the auspices of the British Institution of Electrical Engineers. The American paper has been prepared jointly by Dr. H. H. Lester, Senior Physicist, Watertown Arsenal, Watertown, Mass.; R. L. Sanford, Chief, Magnetic Section, National Bureau of Standards, Washington, D. C.; and N. L. Mochel, Metallurgical Engineer, Westinghouse Electric and Manufacturing Co., Philadelphia, Pa., outstanding authorities on the subjects covered.

The discussion on methods of non-destructive testing is being arranged in three sections covering magnetic and electrical methods; X-ray and gamma rays; and acoustical and general methods. The papers in each section are being prepared by authors representing Great Britain, the continent of Europe and the United States. In addition to the joint American paper which covers the three divisions the following authors are participating:

Magnetic and Electrical Methods—Dr. B. Berthold, Director of the Reichs-Röntgenstelle, Berlin; Dr. A. P. M. Fleming and Mr. B. G. Churcher.

X-rays and Gamma-rays—Ing. J. E. de Graaf, of Philips' Gloeilampenfabrieken, Holland; and Dr. V. E. Pullin.

Acoustical and General Methods—Professor Dr. Köster, of the Kaiser-Wilhelm-Institut für Metallforschung, Stuttgart; and Dr. S. F. Dorey.

It is expected that the Institution of Electrical Engineers will consider issuing the papers and discussion to be presented in a special publication. Further announcement will be made concerning this matter. It is planned to publish the American paper in the ASTM BULLETIN, the expectation being that it will begin with the December issue and possibly be concluded in the January number.

Supplement on Chemical Analyses of Metals

THE recent Circular to Members announced that a supplement to the volume on Chemical Analyses of Metals involving an extensive revision of the Tentative Methods of Chemical Analysis of Ferro-Alloys (A 104-36 T), new designation: E 31-38 T, would be furnished to purchasers and that members could obtain a copy on request. This supplement will become available late in the year.

Schedule of Meetings

| DATE | COMMITTEE | PLACE |
|-----------------|--|----------------------|
| October 19-21 | D-13 on Textile Materials | New York City |
| October 31- | | |
| November 1.. | D-12 on Soaps and Detergents | New York City |
| November 3, 4 | C-1 on Cement | Washington, D. C. |
| November 9... | D-20 on Plastics | New York City |
| November 10, 11 | D-9 on Electrical Insulating Materials | New York City |
| November 10. | DISTRICT MEETING | New York City |
| November 14. | DISTRICT MEETING | Pittsburgh, Pa. |
| March 6-10 .. | COMMITTEE WEEK | Columbus, Ohio |
| March 8 | REGIONAL MEETING | Columbus, Ohio |
| June 26-30 .. | 1939 ANNUAL MEETING | Atlantic City, N. J. |

Joint Committee on Paper Testing

AS A result of recent action by the Executive Committee of the Technical Association of the Pulp and Paper Industry and the A.S.T.M. Executive Committee, there has been appointed a Joint A.S.T.M.-T.A.P.P.I. Committee on Paper Testing. The committee consists of four members, two representing T.A.P.P.I. and two the Society. The following appointments have been made:

Representing T.A.P.P.I.:

P. F. Wehmer, Electrical Testing Labs., New York City
B. L. Wehmhoff, Chevy Chase, Md.

Representing A.S.T.M.:

R. C. Griffin, Treasurer, Arthur D. Little, Inc., Cambridge, Mass.
L. S. Reid, Technician, Standardization Laboratory, Metropolitan Life Insurance Co., New York City

Mr. Reid is serving as chairman of the committee, whose main function will be to promote cooperation of the two associations and to assist in avoiding duplication of work in paper testing methods. It is planned that the committee will review any proposed methods originating in either T.A.P.P.I. or A.S.T.M. before they are submitted finally to the respective associations for approval and adoption. It is greatly to be desired that the two associations agree upon the same method where it is to be used for essentially the same purpose. The two A.S.T.M. committees with whom paper testing methods will originate are D-6 on Paper and Paper Products and D-9 on Electrical Insulating Materials. Provision for cooperation between these two committees has already been made by exchange of formal representation and in other ways.

Offers of Papers for 1939 Meeting

COMMITTEE E-6 on Papers and Publications in anticipation of developing the program for the 1939 Annual Meeting at Chalfonte-Haddon Hall, Atlantic City, June 26 to 30, is desirous that members of the Society and others who have in mind submitting offers of technical papers should send these offers to Society Headquarters well in advance of the February meeting of the committee. All offers must be accompanied by a summary which should make clear the intended scope of the paper and indicate features that in the opinion of the author will justify its inclusion in the annual meeting program. Suitable blanks to be used in transmitting the necessary information will be sent promptly on request.



A Preliminary Consideration of Some Proposed Methods of Sampling and Testing Mortar for Unit Masonry

Editor's Note.—The material which follows has been prepared by A.S.T.M. Committee C-12 on Mortars for Unit Masonry. The committee, reorganized in 1937, has many problems confronting it, and welcomes, indeed requests, constructive comments on the suggested methods of sampling and testing.

THE principal objectives of Committee C-12 on Mortars for Unit Masonry are to write test methods and specifications which will describe how to test mortars and define their required properties so that they will be suitable for service.

In approaching the standardization of tests for masonry mortar or for other construction materials, full preliminary consideration should be given to the various possible methods which may seem to be appropriate to the material and which are practicable for laboratory procedure. The present discussion is intended solely as a presentation of some preliminary thoughts on test methods for masonry mortar and it is hoped that suggestions and criticisms will be stimulated hereby for the guidance of Committee C-12 in its later attempt to prepare adequate and practical standards.

Test methods are the very foundation of specifications and must be decided upon first. Committee C-12 has had preliminary discussion of some proposed methods for testing masonry mortars and those methods, together with the written and oral discussion which has been offered up to date form the basis for the methods suggested herein for further consideration. But by no means are the suggested methods here described final in any sense. They are offered primarily to show the trend of such thoughts as thus far have been expressed by the committee and others. The committee is earnestly desirous of finally arriving at truly indicative test methods and specifications and it hopes to have the criticisms of everyone interested in masonry mortars.

Before discussing test methods it might be well to consider some of the properties of the material with which we are dealing, namely, mortar used for unit masonry construction. The units in masonry construction include brick, block, tile and also stone, both rough stone and carefully finished stone block. The brick mason uses quite a different type of mortar than the stone mason. The brick mason should have a plastic mortar which is easily workable and which will permit of readily filling the joints between the brick. On the other hand, the stone mason dealing with rough, undressed stone block must have a dry mortar, handling like and having the appearance of wet sand. Very plastic mortar would be almost useless to him, for there would be movement of the mortar and stone after placing them in the wall. Although some of the tests herein discussed may apply to the mortar used by the stone mason, primarily they are intended for brick masonry and the present discussion will be limited to the plastic type of mortar.

DESIRABLE PROPERTIES OF BRICK MORTAR

Plasticity.—Brick mortar must be capable of easy handling by the mason. To this end the mortar must be plastic so that it can be spread readily and the horizontal and vertical

joints thus be more easily and completely filled. Plasticity should persist to a certain extent after the mortar is in contact with the brick and this property will not be attained if the water is withdrawn too rapidly by the absorbent brick. Therefore, it seems to be important that the mortar have certain water retention properties. Plasticity in mortar is also of importance because of the better contact which seems to be possible between the brick and the mortar than is the case where non-plastic mortar is used. Plasticity promotes water tightness in a brick wall because of the better filled joints which result from its use as well as because of the better contact between brick and mortar.

Strength of Mortar.—Strength of the mortar is of importance. The mortar should have compressive resistance to develop sufficient strength in the masonry construction. Adhesive strength is also desirable, not only as a measure of protection against shock but likewise for increased resistance against cracking due to unequal settlement.

Setting Properties.—The mortar should have setting properties which will permit of sufficient time for the work to be done properly and which will likewise permit of carrying the construction along rapidly enough. Thus, there should be a minimum and a maximum time of setting.

Soundness.—After the structure is built and subjected to the weather, the mortar should exhibit resistant properties. For illustration, it should be sound in the sense that there will not be undue expansion when the mortar is subjected to dampness or to freezing weather. Nor should there be undue shrinkage with resulting cracking and release of bond. Perhaps there should be some adequate test for this property of volume change.

Non-Staining Properties.—The mortar should not contain undesirable quantities of soluble materials which promote staining of the brick.

Efflorescence.—The efflorescence tendencies of the mortar should likewise be controlled to a desired minimum.

Low Capillary Absorption.—Obviously, also, mortar for brick work should not be highly absorbent after it hardens; that is, it should not carry water through the wall by capillary action.

SUGGESTED METHODS OF SAMPLING AND TESTING MORTAR FOR UNIT MASONRY¹

These suggested methods are published as information only. Comments are solicited and should be addressed to the Headquarters of the Society, 260 S. Broad St., Philadelphia, Pa.

1. **Scope.**—These methods of test apply to the mixtures of cementitious materials and sand used or intended to be used as masonry mortar. Under cementitious materials are included, portland cement, natural cement, slag cement, puzzolan cement, masonry cement, hydraulic lime, hydrated lime, lime putty and mixtures of any of these materials.

¹ Under the standardization procedure of the Society, these suggested methods are under the jurisdiction of the A.S.T.M. Committee C-12 on Mortars for Unit Masonry.



Sand includes the fine granular material resulting from the natural disintegration of rock or from the crushing of friable sandstone rock as well as artificially prepared sone sand and slag sand. These methods of test apply also to mortars containing such admixtures as may be added for the purpose of affecting their properties. They do not apply to mortars made with cementitious material consisting of sulfur, bituminous material, gypsum, magnesium oxychloride, or organic plastics.

DISCUSSION.—The question has arisen as to whether clay should be added to the cementitious materials above enumerated. It has been stated that work done by Messrs. Straight, Bangler, Withey, Collins and Schurecht has indicated increase in strength of mortars caused by substituting clay for lime in certain mixtures. Thus far the committee has expressed itself as against the classification of clay as a cementitious material. Its value as an admixture is recognized.

2. *Sampling: (a) Mortar.*—Samples of mortar for testing may be collected either at the site of the job and be representative of freshly mixed mortar delivered to the mason or they may be prepared in the laboratory from samples of the ingredients. If sampled at the site of the job the samples shall consist of 0.2 cu. ft. of mortar (approximately 30 lb.) and shall be stored and delivered in air-tight metal containers. Not more than 30 min. shall elapse between the time of mixing and time of starting the test. One sample of mortar shall be taken for each 4000 cu. ft. of mortar or for each new shipment of sand or cementitious material, or when other conditions arise on the job which may make it advisable to test additional samples. When the mortar is mixed in the laboratory, each sample of the cementitious material provided shall weigh at least 8 lb. and shall represent not more than 300 bbl.

(b) *Cementitious Materials.*—The cementitious materials shall be sampled in accordance with the methods of the American Society for Testing Materials for sampling these respective materials, as follows:

Portland Cement.—Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation: C 77).²

Masonry Cement.—Tentative Specifications for Masonry Cement (A.S.T.M. Designation: C 91).³

Natural Cement.—Standard Specifications for Natural Cement (A.S.T.M. Designation: C 10).⁴

Quicklime and Lime Products.—Standard Methods of Sampling, Inspection, Packing and Marking of Quicklime and Lime Products. (A.S.T.M. Designation: C 50).⁵

(c) *Sand.*—The sample of sand shall weigh not less than 25 lb. and shall be sampled in accordance with the Standard Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials, Including Some Materials Survey Methods (A.S.T.M. Designation: D 75) of the American Society for Testing Materials.⁶

² 1937 Supplement to Book of A.S.T.M. Standards, p. 54.

³ *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I (1938); also 1938 Book of A.S.T.M. Tentative Standards.

⁴ 1937 Supplement to Book of A.S.T.M. Standards, p. 52.

⁵ 1936 Book of A.S.T.M. Standards, Part II, p. 68.

⁶ *Ibid.*, p. 1092.

⁷ The use of 5.5 g. of material for each pound of the cementitious material and sand in a one-bag batch usually will provide a weight of dry mortar within the prescribed limits. For illustration, assume that the mortar mix specified consists of one sack of cementitious material, weight, 65 lb., and 3 cu. ft. of sand. The laboratory mix would then be:

Cementitious material = $65 \times 5.5 = 357.5$ g.
Sand = $75 \times 3 \times 5.5 = 1237.5$ g.

Total dry materials = 1595 g.

(d) *Admixtures.*—Samples of any admixtures intended for use in mortar shall be of sufficient size to provide a specified amount of admixture in 0.2 cu. ft. of mortar.

DISCUSSION.—The question has arisen as to whether the sample representing 300 bbl. should be stated as a sample representing so many tons of cementitious material; also, the question as to whether one sample for each 300 bbl. of cementitious material is not excessive. In this connection it may be stated that this part of the suggested method of sampling is in line with that for portland cement in which a 300-bbl. unit is used.

Is it proper to take samples of mortar from the job for use in test specimens? There is some difference in opinion on this point. There seems little doubt, however, that if it is desired to test the quality of mortar actually being used on the work, provision must be made for obtaining samples of the mixed mortar. Such a provision is made in connection with the sampling of concrete and there seems to be just as much reason for obtaining field samples of mortar as of portland-cement concrete.

The question of sampling lime putty has been discussed by one of the members of the committee and he suggests that lime putty be sampled by the use of a brass sampling tube 1.6 in. in internal diameter and 6 in. in length. The tube is pushed into the putty bed and withdrawn full, capped at one end and struck off level at the other. The purpose of this type of sample is to determine the lime solids per cubic foot. Additional lime putty, at least 8 lb., should also be taken for other tests. The sampling of lime putty needs further study by the committee.

3. *Proportioning of Mortar Sample.*—(a) The method of proportioning described herein is intended to duplicate in the laboratory the proportions used on the work. In general, field proportions are designated by volume. The proportions of the mortar made in the laboratory shall be in accordance with the proportions specified for use on the work. For the purpose of proportioning, the net weight as marked on the bag shall be taken as the net weight of the cementitious material per cubic foot.

(b) In the absence of information as to weight, the weight per cubic foot shall be determined by loose measure. Portland cement shall be considered as weighing 94 lb. per cu. ft., and hydrated lime as 40 lb. per cu. ft. A cubic foot of sand shall be considered as containing 75 lb. of sand in an air-dry condition and this value shall be used for purposes of proportioning. Admixtures shall be used in the proportions specified. Where lime putty is used in the mortar, 40 lb. of lime solids in the form of putty shall be considered as 1 cu. ft. of lime.

DISCUSSION.—In oral discussion it was stated that if ground clay is to be used as one of the cementitious materials its weight should be considered as 64 lb. per cu. ft.

4. *Method of Mixing Mortar.*—(a) The mortar shall be mixed in a non-absorbent bowl of about 1-gal. capacity. A measured quantity of water, less than that required to give the prescribed flow, shall be poured into the bowl which has previously been wiped with a damp cloth. The quantity of dry mortar materials mixed at any one time shall be not less than 1500 g. nor more than 1800 g.⁷

(b) The dry cementitious material and dry sand shall be weighed separately to the nearest 1 g. The cementitious material shall be added and stirred into the water with the fingers of one hand until all the cement is wetted. Approximately one-third of the quantity of sand shall then be added and the stirring continued for 30 sec. The remainder of the sand shall then be added and the mortar mixed for 75 sec. by vigorous and continued stirring, squeezing and kneading with one hand. The mortar shall then be allowed to stand for 60 sec. and then mixed for another 60 sec. The flow of the mortar shall be adjusted by the addition of water so that it is within the limits specified. After each addition of water, the mortar shall be mixed for 60 sec. During the



operation of mixing, the hands shall be protected by rubber gloves.

DISCUSSION.—A portion of this method of mixing mortar agrees with the method specified in the Tentative Method of Test for Compressive Strength of Portland-Cement Mortars (A.S.T.M. Designation: C 109).⁵ It would seem desirable to bring these two methods into line for the sake of simplification in laboratory procedure.

The above suggested method applies to dry materials and as lime putty is one of the important masonry mortar materials, the methods finally standardized should be made suitable for this material also.

5. Time of Setting.—Time of setting shall be determined by the Gilmore needle method in accordance with Sections 39 and 40 of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation: C 77) of the American Society for Testing Materials.² The test specimen shall be a pat of mortar with a flow of 100 to 115 per cent as measured by the 10-in. flow table with a drop of 0.5 in. (see Section 7). The mortar pat shall be stored during the time of setting test in a damp closet maintained at a relative humidity of 90 per cent or more. Zero time shall be counted from the completion of the mixing of the mortar.

6. Compressive Strength of Mortar.—Mortar used for making specimens for compressive strength tests shall have a flow of between 65 and 80 per cent. The molds for making compression test specimens shall conform to Section 4 of the Tentative Method of Test for Compressive Strength of Portland-Cement Mortars (A.S.T.M. Designation: C 109) of the American Society for Testing Materials.⁹ The testing machine shall be in accordance with Section 5 of Tentative Method C 109. The method for filling the molds, storing of specimens, testing of cubes, and calculation of compressive strength shall be in accordance with Sections 12 to 15, inclusive, of Tentative Method C 109.

DISCUSSION.—In discussion at the meeting of Committee C-12 in Pittsburgh, Pa., on March 18, 1938, a number of questions arose regarding compressive strength. Should an attempt be made to simulate the absorption effect of brick in reducing the water content of the mortar? Should absorbent molds be used? The point was also made that mortar in thin sections existing in a joint has higher compressive strength than will be found in a test specimen as ordinarily made. The question of curing in connection with compression testing was also discussed. It is of course a fact that the method of curing above described is detrimental to non-hydraulic mortars. It has been suggested that the method of storage of test specimens as prescribed in the Tentative Specifications for Masonry Cement (A.S.T.M. Designation: C 91),⁶ Section 22, be used. This method reads as follows:

Storage of Test Cubes.—All test specimens, immediately after molding, shall be kept in the molds on plane plates in a damp closet, maintained at a relative humidity of 90 per cent or more for from 48 to 52 hr. in such a manner that the upper surfaces shall be exposed to the moist air. The cubes shall then be removed from the molds and placed in the damp closet for 5 days in such a manner as to allow free circulation of air around at least five faces of the specimens. At the age of 7 days the cubes for the 28-day tests shall be immersed in clean running water in storage tanks of non-corrodible materials.

DISCUSSION.—Tentative Method C 109 calls for storage in the moist closet for 24 hr. then immersion in clean water until tested. The method of storage is highly important because of the diverse character of the cementing materials which may have to be tested. In view of the critical effect of storage on the compressive strength of the mortar and the evident difference of opinion on this matter within the committee, there should be very full discussion of the

reasons for and against the methods which have been proposed or which may be proposed.

Mr. F. O. Anderegg has pointed out that storage of specimens wet will be unfair to certain types of mortar. The alternate proposal to store in the damp closet would be much fairer, but even then there is grave doubt that the conditions on the actual job would be anywhere near approximated. Storage for the first seven days in the damp closet and then in the air of the laboratory is suggested.

7. Consistency (Flow): (a) Apparatus.—The flow table apparatus shall consist of a rigid frame with a flat circular top, so mounted on a vertical shaft that it can be raised and dropped through a fixed height of 0.5 in. by means of a rotated cam. The top shall be of non-corrodible metal 10 in. in diameter and with the attached shaft shall weigh 9 ± 1 lb. The frame shall be attached rigidly to a concrete pedestal, which in turn shall be attached rigidly to the floor. The concrete pedestal shall be at least 8 in. in diameter and 25 in. in height and shall weigh at least 100 lb. The mold shall be of a non-corrodible material, 4 in. in inside diameter at the base, $2\frac{3}{4}$ in. at the top, and 2 in. in height.

(b) Procedure.—In making the determination, the flow-table top shall be carefully wiped dry and the flow mold placed at the center and filled with mortar. Immediately after completing the mixing operation the mold shall be filled with mortar not by ramming, but by gently compacting to insure uniform filling. The mortar shall be smoothed off level with the top of the mold by aid of a trowel and the mold removed. Immediately the table shall be dropped through a height of 0.5 in. 25 times in 15 sec. The flow is the resulting increase in diameter of the mortar mass, expressed as the percentage of the original diameter.

DISCUSSION.—No particular objection has been offered to the method of test described in Section 7 except that its accuracy has been questioned. It has been pointed out that a slight inaccuracy of only $\frac{1}{8}$ in. in flow may make a large difference in the water-cement ratio. Perhaps when the committee writes specifications this may be taken into account by the use of proper permissible variations in the specification limits.

8. Water Retention: (a) Apparatus.—For the water retention test an apparatus essentially the same as that shown in Fig. 1 shall be used. This apparatus consists of a water aspirator controlled by a mercury column relief and connected by way of a three-way stop-cock to a funnel upon which rests a perforated dish. A mercury manometer connected as shown in Fig. 1 indicates the vacuum. A rubber gasket shall be sealed to the top of the funnel and shall be kept wet during a test to insure a seal between the funnel and dish. The perforated dish shall be made of a non-absorbent material. Hardened filter paper equivalent to Carl Schleicher and Schull filter paper No. 575 shall be used. It shall be of such diameter that it will lie flat and completely cover the bottom of the dish.

(b) Procedure.—The mortar shall be mixed as described in Section 4 to a flow of from 100 to 115 per cent. Immediately after making the flow test, the mortar on the flow table shall be remixed with that remaining in the mixing bowl for 30 sec. Immediately after remixing, the mortar shall be uniformly distributed without compacting over the sheet of dampened filter paper in the perforated dish and the surface leveled off flush with the rim of the dish by drawing a straight edge across the dish with a slightly sawing motion. The dish shall then be set on the wetted gasket, and with the mercury column set at 2 in., the stopcock shall be turned to apply the vacuum to the funnel. After suction for 60 sec., the stopcock shall be quickly turned to expose

⁵ Proceedings, Am. Soc. Testing Mats., Vol. 38, Part I (1938); also 1938 Book of A.S.T.M. Tentative Standards.

⁶ Proceedings, Am. Soc. Testing Mats., Vol. 37, Part I, p. 726 (1937); also 1938 Book of A.S.T.M. Tentative Standards.

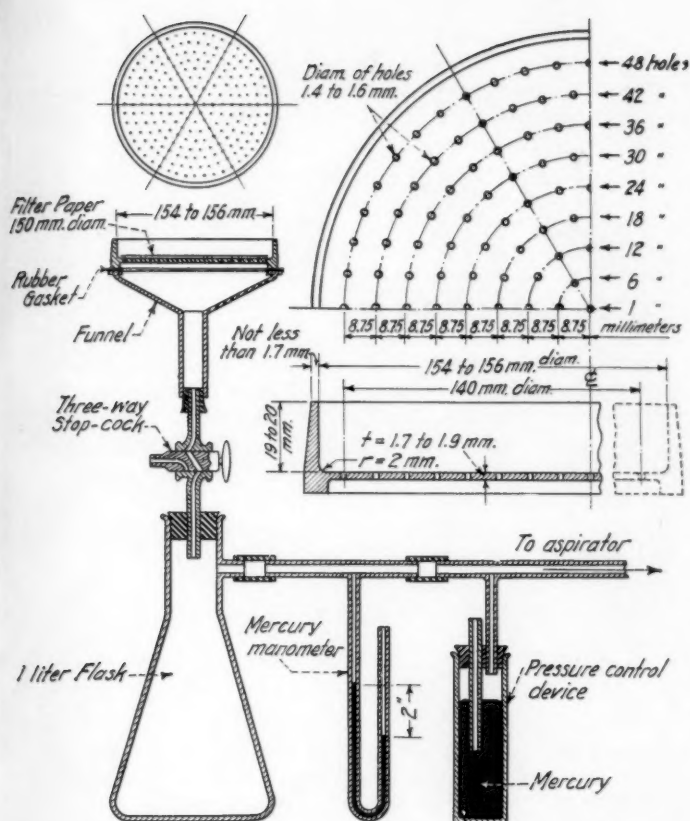


Fig. 1.—Apparatus Assembly for Water Retention Test.

the funnel to atmospheric pressure. The contents of the dish shall then be immediately removed by means of a putty knife or square-end spatula and placed in the mold on the flow table. As each portion of mortar is placed in the mold it shall be well puddled with glove-covered fingers. When the mold is filled, the mortar shall be smoothed off level with the top of the mold using the edge of trowel, and the flow determined as previously. The entire operation shall be carried out without interruption and as quickly as possible and shall not require more than 7 min. for completion, starting from the completion of the mixing of the mortar for the first flow determination. Both flow determinations shall be made in accordance with the procedure described in Section 7, special care being taken to fill the mold uniformly when obtaining the flow after suction.

DISCUSSION.—The age of the mortar after mixing has an effect on water retention. It has been suggested by Mr. H. M. Huntzicker that the mortar should be mixed initially to a flow of approximately 100 to 115 per cent and allowed to stand for 30 min. At the end of this period the mortar should be retempered if necessary to bring the flow to between 100 and 115 per cent at which time suction should be applied. A maximum time of 6 min. should be allowed for making the first flow test, the 60-sec. suction and the final flow test. It is his belief that these revisions will make the test fairer for those cements which increase in plasticity and water retention on standing and they will not penalize other materials. The fact that certain masonry cements gradually take on better water-retention qualities on standing, and in some cases become stiffer, makes it imperative according to Mr. Huntzicker that the time elapsing between the initial and final flow test be as small as possible. He calls attention to the fact that the test methods are accurate to only plus or minus 6 per cent and that when specifications are written proper permissible variations should be recognized. The question of specifying a standard suction cup (identical with that used by the Bureau of Standards) seems also to be very important. Reference should also be made as to where this cup can be obtained.

Mr. Anderegg states that in all work on masonry cements and mortars it has been his custom to allow the half hour of soaking.

and he strongly emphasizes Mr. Huntzicker's suggestion of allowing the mortar to stand for 30 min. On the job, it is exceptional for the mortar to be used in a shorter time than this and since time is required and is given practically on the job, for moisture absorption by the plasticizing ingredients in the cementitious material, this should be allowed for in the test.

The possibility of using several other methods has been mentioned and one very interesting development in connection with (a) the workability or fatness of mortars and (b) the water retention of mortars is that devised by Mr. L. A. Wagner while employed by the cement reference laboratory of the National Bureau of Standards. A photograph of Mr. Wagner's device is shown in Fig. 2 and is called a mixing bowl plasticimeter. This device is used for measuring the fatness of masonry cements. It consists essentially of an electrically driven pan mounted on a vertical axis; a paddle also mounted on a vertical axis tends to rotate with the mortar but is prevented from doing so through a system of levers arranged so that the resistance required to prevent rotation may be measured by means of weights on a scale pan. Mr. Wagner has said, "The conceptions on which the test is based may be stated as follows: It is assumed that the plasticimeter measures stirring resistance. Next, it is assumed that stirring resistance is inversely proportional to additive factors, namely, (1) wetness of the mortar and (2) fatness of the cement. Finally, it is assumed that wetness is indicated by the flow table. Hence, if stirring resistance is made constant, then fatness becomes inversely proportional to flow." It would seem that this device would lend itself to the determination of one of the properties desired in brick masonry mortars, namely, sufficient plasticity.

Mr. J. C. Pearson uses a modification of the water-retention test described in Section 8 to the extent of applying the Gilmore needle to the surface of the mortar as suction is being used in the porous-plate suction apparatus.

9. *Soundness and Volume Change: (a) Preparation of Specimen.*—The mortar shall be mixed as described in Section 4 to a flow of from 70 to 80 per cent as measured by the flow table described in Section 7(a).

(b) *Molding*.—Immediately after mixing four 1 by 1 by $6\frac{1}{4}$ -in. prisms shall be made in non-corrodible metal molds. Stainless steel screw insets $\frac{5}{8}$ in. in length shall be inserted into recesses centered at both ends of each mold. Mortar shall be carefully and firmly pressed about the insets with the gloved forefinger. Molds shall then be filled alternately in layers approximately one-third the depth of the mold. Beginning at one end of the mold, the operator shall compact each layer by tapping with the gloved forefinger 12 times in moving to the opposite end of the mold and 12 times in returning to the starting point. This procedure shall be performed twice on each layer. After the top layer

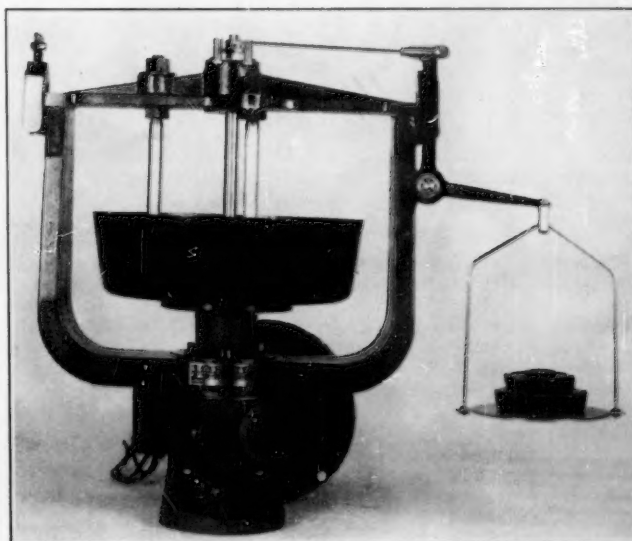


Fig. 2.—Mixing Bowl Plasticimeter

has been compacted, the mold shall be smoothed off with a trowel and marked.

(c) *Storage*.—Prisms with top surfaces exposed shall be stored in a moist room maintained at a relative humidity of 90 per cent and a temperature between 65 and 75 F. (18 and 24 C.) for 48 to 52 hr. They shall then be immersed in water for 2 hr. before testing.

(d) *Autoclave Tests*.—At least three prisms of each mortar, aged as indicated not less than 50 hr. nor more than 56 hr., shall be surface dried with a towel and carefully measured to 0.0001 in. in a comparator. They shall then be placed on a rack in an autoclave and subjected to saturated steam at a pressure of 150 psi. within 1 hr. After the pressure has been maintained constant at 150 psi. for 3 hr., it shall then be gradually released within a period of 5 min. Then the prisms and rack shall be removed, immersed in water at 150 F. (65 C.), and cooled to room temperature in a period of not less than 30 min. Specimens shall then be surface dried and measured.

(e) *Comparator Measurements*.—For purposes of such measurement a comparator equipped with a dial gage graduated to 0.0001 in. is suggested. The temperature of specimens at initial and final measurement shall not differ more than 3 F. (1.7 C.). The comparator shall be provided with a standard gage bar for checking readings.

DISCUSSION.—The test for volume change described by Rogers and Blaine has been suggested. The test consists of molding 1 by 1 by 8-in. prisms in collapsible molds. Each mold is lined with wax paper, and before filling with mortar, a glass plate $\frac{7}{8}$ in. in diameter is placed in the bottom. The mortar is gently rodded into each compartment, and after filling, a small glass plate, similar to the one at the bottom, is placed upon the top. The mold is then set underneath the dial micrometers and the changes in length measured to 0.005 per cent. The gages are so placed that their stems rest upon the centers of the top glass plates. They are read immediately and then hourly for the first 7 hr. When the specimens are sufficiently strong, usually at the end of 30 hr., they are measured, removed from the mold and placed in a damp closet for 1 week. If sufficient strength is not obtained in 30 hr., storage in the damp closet shall be in the molds. At the end of 7 days storage in the damp closet, the bars shall be remeasured and then dried for 1 week in an oven at 65 C. Measurement after drying shows, according to Rogers and Blaine, almost as much shrinkage as that produced by 1 year's drying at laboratory temperature.

If an autoclave test is to be used as a test method, it would seem desirable to have a standard procedure for making this test on mortars. Committee C-1 on Cement, for illustration, makes use of a 10-in. bar with 295-lb. pressure instead of the 150-lb. pressure above suggested. It has been stated by Mr. H. F. Gonnerman that 5 min. is too short a time for the release of the pressure and he recommends the release of pressure in 1 hr. down to 212 F. (100 C.), then immersing the specimen in boiling water and finally cooling that water down to the proper temperature in about 30 min.

In a written discussion Professor Voss has stated that the section on soundness and volume change should not appear in the test methods. He believes that it will not indicate the real behavior and is dependent upon the nature of the cementitious materials. He believes that volume changes due to cycles of wetting and drying are more significant, but that they require too much time and are too expensive for the ordinary laboratory.

Judging from results presented to the committee by Professor Withey, making use of the autoclave test, there are good reasons for believing this test has value in detecting the presence of unhydrated lime or magnesia which, upon hydration, may expand to a troublesome extent. The results are not available for the purpose of discussion in this report, but these as well as other results should be taken into account in a final decision as to whether the autoclave test should be included among the test methods.

Mr. Anderegg has suggested that we have an excellent opportunity of inaugurating a series of cooperative tests, and that while these are being made, experiments on the effect of different types of storage on different types of masonry mortars could very well be carried out.

10. *Staining (Water-Soluble Alkali)*.—The determination of water-soluble alkali shall be made as follows:

(a) To a 150-g. sample placed in a 400-ml. beaker add 250 ml. of distilled water. Stir thoroughly, let stand 30 min. at room temperature, and stir again. Filter through a Büchner funnel, transfer the insoluble matter to the original beaker and rinse the funnel with 150 ml. of distilled water into the beaker containing the insoluble matter. Stir thoroughly, let stand 30 min. at room temperature, and stir again. Filter as above and again return the insoluble matter to the original beaker. Wash the funnel with 100 ml. of distilled water into the beaker containing the insoluble matter. Stir thoroughly, let stand 30 min. at room temperature, and stir again. Filter as above.

(b) Acidify filtrate with HNO_3 and evaporate to 50 ml. Make slightly basic with ammonia and add solid $(\text{NH}_4)_2\text{CO}_3$ to the hot solution in excess. Filter hot and wash with hot ammonia solution (1 per cent). Discard precipitate.

(c) Acidify the filtrate with HNO_3 and evaporate to dryness. Heat until fuming ceases. This step may be done in acid or basic solution, but the evaporation is faster in acid solution and the solution does not show as much tendency to bump.

(d) Dissolve the ignited residue in 20 to 30 ml. of hot distilled water. Add three drops of ammonia, 1 ml. of $(\text{NH}_4)_2\text{CO}_3$ solution (5 per cent), and 1 ml. of $(\text{NH}_4)_2\text{C}_2\text{O}_4$ solution (4 per cent) while hot. Stir and allow to settle 5 min. Filter and wash as before. Discard precipitate.

(e) Acidify filtrate with HNO_3 , evaporate to the absence of fumes, ignite. Dissolve residue in 10 ml. of distilled water and transfer to a tared platinum dish, washing out beaker well. Add 1 to 2 ml. of concentrated H_2SO_4 and slowly evaporate to dryness. Care shall be used in this step. The acid should be thoroughly stirred with the solution before applying heat for evaporation. Ignite until fumes cease to come off, cool in a desiccator, weigh, and calculate as Na_2O , as follows:

$$\text{Percentage of Na}_2\text{O} = \frac{\text{Weight of Sulfates} \times 0.4364 \times 100}{\text{Weight of sample}}$$

NOTE.—The amount and nature of the staining material in limestones seem to vary with the stone. The alkali in any cement may therefore induce markedly different staining on different stone, even though the stone may have come apparently from the same source. The amount of alkali permitted should not cause stain unless stone high in staining material has been used or unless insufficient means have been used to prevent infiltration of water into the masonry.

DISCUSSION.—Professor Voss sees no objection to the method as described, but feels it is irrelevant as stated. He questions whether all of the compounds have been taken into account and thinks that the staining test can be eliminated from the suggested methods. Mr. F. O. Anderegg says that staining is due to alkalies, that water-proofing reduces staining and that salty sands near the sea coast may also have a staining effect. Organic material in the mortar has also been shown to have a staining effect sometimes attributed to iron compounds.

11. *Efflorescence: (a) Materials Required*.—Clay or shale building bricks of such porosity that they will wet through from end to end in less than 5 hr. when stood on end in $\frac{1}{2}$ in. of distilled water shall be provided. The bricks shall not rate more than "Trace" on the scale for measuring efflorescence described in Paragraph (c) when tested by being exposed to the air of the laboratory for 5 days while standing on end in $\frac{1}{2}$ in. of distilled water. Sufficient mortar, mixed according to Section 4 and having a flow of between 100 and 115 per cent (Section 7) shall be provided to coat the brick in the manner prescribed in Paragraph (b).

(b) *Preparation of Test Specimens*.—A coating of mortar $\frac{1}{2} \pm 1/16$ in. in thickness shall be applied to one end

and both flats and faces of a dry brick having the properties described in Section 11(a). The mortar shall extend $2 \pm \frac{1}{4}$ in. from the mortared end. Care shall be taken to avoid smearing mortar on the exposed surface of the brick. The specimen shall be cured by exposing the brick, mortar end up, for 58 hr. in the air of the laboratory.

(c) *Procedure*.—The cured specimen shall be stood, mortar-end down, in 1 in. of distilled water for a period of 5 days exposed to the air of the laboratory. At the same time another brick, without mortar, shall be likewise stood on end in 1 in. of distilled water contained in a separate container. The water level shall be maintained approximately constant by suitable devices. The appearance of the brick-mortar specimen shall be compared with that of the bare brick and their efflorescence rating shall be compared according to the following scale:

- (0) None. . . . No observable difference in the appearance of a brick after test and before.
- (1) Trace. . . . Efflorescence barely distinguishable by careful comparison.
- (2) Slight. . . . Observable. Not sufficient efflorescence to affect materially the appearance when viewed at a distance of approximately 6 ft.
- (3) Moderate. . . . Distinct coating but the original color of the brick distinguishable under the efflorescence.
- (4) Considerable. . . . The original color of the brick masked by the efflorescence.
- (5) Abundant. . . . Efflorescence in such quantity that it may be brushed off readily.

DISCUSSION.—It has been stated that the use of a brick is not necessary in this test, for more efflorescence can be obtained by the use of a mortar specimen alone. This point perhaps should be considered further and a standard method written, omitting the use of a brick in making the test. Professor Voss would use the same brick as advocated by him for use in making a bond test, otherwise he would make the test in the manner described.

Mr. Anderegg states that he likes the wick test on the mortar alone, and prefers not to complicate it unless there is reason to suspect interaction between constituents leached from the mortar and others in the brick, for example, the formation of sodium vanadate. In that case the actual brick to be used on the given job should be used in this test.

12. *Water Repellency*.—For making the water-repellency tests the mortar shall be mixed as described in Section 4 to a consistency of 100 to 115 per cent as measured by the flow test described in Section 7. Three cubes shall be cast in 2-in. molds without oiled or greased surfaces as described in Section 6. The specimens shall be kept in the molds on plane plates in a damp closet maintained at a relative humidity of 90 per cent or more for from 48 to 52 hr. in such a manner that the upper surfaces shall be exposed to the moist air. The cubes shall then be removed from the molds and placed in the air of the laboratory for 5 days in such a manner as to allow free circulation of air around at least five faces of the specimens. At the age of 7 days they shall be placed in a drying oven maintained at a temperature of 105 to 110 C. for 20 to 24 hr., then removed, placed in air at 21 ± 3 C. for 2 hr., weighed to the nearest 0.5 g. and then placed in water at 21 ± 3 C. to a depth of $\frac{1}{4}$ in., with the top side as cast placed downward. At the end of 1 hr. the specimens shall be removed, drained for 5 min. and if any excess water still remains on the specimens it shall be removed with a damp cloth. The specimens shall then be weighed. The increase in weight gives the 1-hr. absorption. The specimens shall then be replaced, $\frac{1}{4}$ in. immersed in the water and 24 hr. after immersion again removed, drained, wiped

DISCUSSION.—Mr. Anderegg states that he does not think any test on mortars should be made involving heating to 105 C. Irreversible changes in the mortar are very apt to occur. The test should

as above, and weighed. The increase in weight over the original dry weight gives the 24-hr. absorption.

be made on compression specimens, say stored 48 hr. in the damp closet and then 7 days in the air of the laboratory and the absorption rate curve then determined. This should be carried out, whenever possible, with the waterproofing material and without it.

There is some question as to the infallibility of such a test, for mortars waterproofed with stearates are effective when the stearates are wet, but not when they are dry, and the test method as above described calls for drying the specimens in an oven before being subjected to the test.

13. *Freezing-and-Thawing Test (a)*.—Ten 2 by 4-in. cylinders shall be molded of each mortar according to standard procedure. These shall be stored in a damp chamber for 28 days prior to the freezing cycles. Five of the specimens shall then be immersed in water (without boiling) for 6 hr. They shall then be set in pans on end in 0.5 in. of water, in which condition they shall be frozen at -10 C. during the next 18 hr. This cycle shall be repeated 30 times.

(b) The other five specimens shall be stored in water 30 days while the first five are being frozen, thus making their storage similar to the specimens being frozen. The compressive strength of these shall then be compared with that of the frozen specimens and the percentage decrease in strength due to freezing shall be used as a measure of the resistance of the mortars to freezing. In case the specimens disintegrate before 30 cycles are completed, the number of cycles before disintegration should be noted.

DISCUSSION.—The test in Section 13 was criticized as discriminating against non-hydraulic and low-strength mortars when tested at 28 days.

Mr. Anderegg has suggested that more evidence as to the effect of freezing and thawing on present day mortars should be accumulated. For instance, old time lime mortars can be found, which have given long service in unexposed positions which would go to pieces in one or two freezings. Where they have been exposed to the weather, of course, as in chimneys and parapet walls, they have disintegrated badly. We need to accumulate experimental and observational data in a systematic manner. This again might well be attempted in a series of cooperative tests.

14. *Bond Tests: (a) Test Specimens*.—Bond tests shall be made for mortars by the preparation of 3 specimens made of 2 bricks each laid crosswise with their largest faces in contact and with a joint 0.5 in. in thickness. The brick shall be a smooth-faced dry-pressed brick with such porosity that they will wet through from end to end in less than 5 hr. when stood on end in 0.5 in. of distilled water. They shall have a 48-hr. absorption of not less than 5 per cent nor more than 10 per cent and shall be of a homogeneous structure. The mortar prepared as in Section 6 shall be bedded upon the lower of each set of two at least $\frac{3}{4}$ in. in thickness and the top brick shall be tapped firmly onto this bed of mortar until the joint is approximately 0.5 in. in thickness and so that both brick are approximately centered, level, and at right angles to each other. Devices for the centering of brick may be used. After each assemblage is made it shall be thoroughly jointed to a square, well-filled joint with a flat center.

(b) *Storage of Test Specimens*.—Specimens shall be left in the air of the laboratory for at least 20 hr. and shall then be stored in a damp room or closet according to Section 22 of the Tentative Specifications for Masonry Cement (A.S.T.M. Designation: C 91)¹⁰ of the American Society for Testing Materials.¹⁰

(c) *Apparatus*.—The testing machine shall be in accordance with Section 5 of the Tentative Methods of Test for Compressive Strength of Portland-Cement Mortars (A.S.



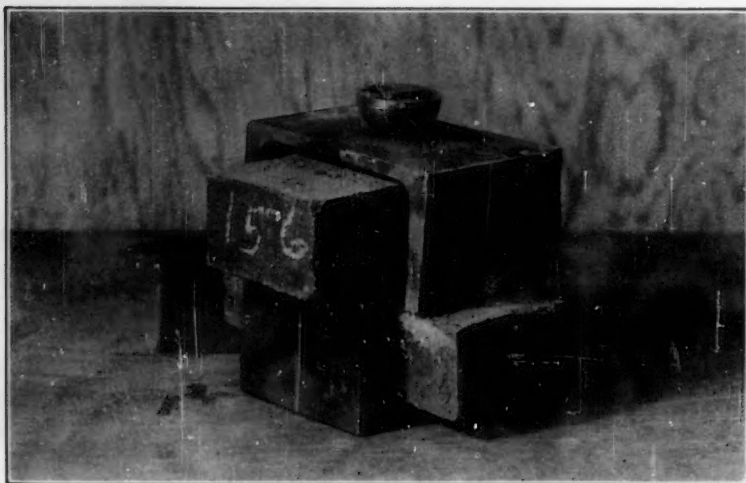


Fig. 3.—Tension Bond Test Specimen

T.M. Designation: C 109) of the American Society for Testing Materials.¹¹ Results shall be recorded as an average of all three assemblages. The brick which is to be used in any particular project may be substituted for the standard brick given above.

(d) *Procedure.*—The specimens shall be tested between two channel-iron clips made as shown in Fig. 3 and provided with three-point bearings on each pair of channel toes. These clips shall weigh approximately 5 lb. each and shall be placed symmetrically under and above the specimen. The top channel shall be provided with a centered vertical depression into which a 2-in. hardened steel hemisphere may rest evenly. The specimens shall be centered in the testing machine and put under compression. The load at failure and the bonding strength in pounds per square inch of carefully measured bonded area shall be calculated and recorded. The percentage of breaks in the mortar and at the brick plane shall be recorded to the nearest 5 per cent of the area in bond.

DISCUSSION.—Mr. Anderegg states that he believes the bond test to be of great value, whether made in tension, as suggested, or whether a small column, say 9 brick high, is laid up and later broken in flexure.

He would like to see clay included in the list of cementing materials. It certainly has cementing action and has been used for many thousands of years and is still being used extensively by itself as a cement. He uses it in the highest strength mortars, those used in pre-stressed masonry beams, and he has readily obtained strengths similar to the ceramic tile units.

Professor Voss who has proposed the bond test in Section 14 also feels that compressive strength tests should be made on assemblages as follows:

Compressive Strength of Assemblages, Specimens and Storage.—Compressive strength tests shall be made by the preparation of three specimens made of two halves each of three bricks bedded upon each other in accordance with Section 14(a). The specimens shall be stored in the same fashion as the bond test specimens and as given in Section 14(b).

Tests.—The specimens shall be prepared for test in accordance with the Standard Methods of Testing Brick (A.S.T.M. Designation: C 67)¹² Sections 2 to 6, inclusive. The total load at the first drop of the beam or recession of the pointer shall be recorded as the load at failure. This shall be recorded as failure at psi. or the basis of the carefully measured bonded area and shall be the average of the three specimens.

CONCLUSION

It will be observed that in the test methods as they have been proposed thus far, no mention has been made of the testing of the constituent materials in the mortar. It is to be presumed that later on when specifications are written, the constituent materials will be specified, either by reference to standard specifications which already have been written by some other committee of the Society, or, in their absence, by writing a specification for the materials concerned. In those cases where materials are not already specified in standards of the Society it will be necessary to write test methods for those materials, among them being fine aggregates and possibly admixtures. It is recognized, therefore, that the test methods in their present state are incomplete and to them will have to be added methods for testing constituent materials which can be used in purchase specifications.

¹⁰ *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I (1938); also 1938 Book of A.S.T.M. Tentative Standards.

¹¹ *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 726 (1937); also 1938 Book of A.S.T.M. Tentative Standards.

¹² 1937 Supplement to Book of A.S.T.M. Standards, p. 78.

Inspection of Cement Testing Laboratories

THE Cement Reference Laboratory, a joint project of the National Bureau of Standards and the American Society for Testing Materials and sponsored by Committee C-1 on Cement, is now preparing for a sixth inspection tour among cement testing laboratories. Those laboratories which desire to avail themselves of this inspection service should promptly address their requests to the Cement Reference Laboratory at the National Bureau of Standards. The proposed tour will, in general, provide only one opportunity for the inspection of any laboratory during the next two years. The inspection work is limited to physical tests of cement and does not include the calibration of compression testing machines.

Literature on Gray Iron Properties

A CRITICAL study of the world's technical literature on the properties of gray iron has been started at Battelle Memorial Institute by the Gray Iron Founders' Society, Inc. It is planned to present the data gathered by the Battelle metallurgists in a form particularly adapted to the needs of the member foundries. Much valuable information on the engineering properties of modern gray iron can be found in technical publications, but not usually in accessible and convenient form for practical use. It will be the task of the Battelle staff to select the most useful and authoritative of this material and to shape it for the use of foundrymen, engineers, and purchasing agents.

Cooperative Study of Methods of Determining Free Lime in Portland Cement and Clinker¹

By W. C. Hanna,² T. A. Hicks,² and G. A. Saeger²

THIS study was undertaken with the view of recommending for consideration by the Society a method or methods for determination of free lime where a limit on free lime is specified by a consumer. We feel it is advisable to emphasize the fact that as far as A.S.T.M. test methods are concerned, accuracy and precision are of primary importance. The cost in time and equipment and speed of any method must be taken into consideration but they are of secondary importance. The method that is best for plant control is not necessarily the best for the purposes of the A.S.T.M. The ideal is a method suitable for all purposes. When such is not available, it may be well to select two methods. One of them could be known as the standard method and to govern in case of dispute. Its degree of accuracy and precision should be as high as possible without the cost being prohibitive or the manipulation being too difficult for general use.

The other method known as the alternate method may be more rapid or more economical to use. It should possess a fair degree of accuracy and precision. It may be used for plant control if so desired.

SAMPLES

Three samples of clinker and two of cement were used in this work and are known to the working committee as Samples N, O, P, Q, and R.

Samples N and O were manufactured from identical commercial raw materials in a commercial kiln. The raw mix was of standard composition but the burning was carried out so as to have one sample low and the other high in free lime. The clinkers were crushed and ground with laboratory machinery.

Sample N was "hard-burnt" and Sample O was "soft-burnt." Their determinations of loss on ignition were 0.1 and 0.4 per cent respectively. There was no gypsum in them. They represented extremes that might be encountered in commercial practice.

Sample P was clinker which was distributed without crushing and grinding. It was composed of 54 per cent hard-burned clinker (Sample N) and 46 per cent soft-burned clinker (Sample O). The weight of the original sample of the hard-burned clinker was about 210 lb. It was halved by rippling and one half was used for Sample N. There was also about 180 lb. of soft-burned clinker. It was halved by

rippling and one half was used for Sample O. The remaining clinkers were mixed thoroughly by shoveling and then divided continuously by rippling until there were 64 portions weighing about 3 lb. each. The first 46 portions were distributed to the cooperating laboratories.

This use of coarse clinker was intended to ascertain whether it was possible for a three-pound sample to be truly representative of a four hundred-pound lot and whether the various methods of final preparation employed by the cooperating laboratories would produce an abnormal degree of variation in the determination of free lime. We took such a mixture of extremes in order to simulate commercial sampling which could possibly involve such a mixture.

Sample Q was aged portland cement of standard composition picked up on the market. It was received in a lumpy condition and was ground a few minutes in a laboratory mill to break up the lumps. Its loss on ignition was 1.7 per cent. It was used to study the effect, if any, of aging on the determination of free lime and to see if there is a method that is satisfactory for both fresh clinker and commercially ground cement.

Sample R was dark-colored portland cement. It was drawn from a plant bin and was free of lumps. It contained 5.7 per cent ferric oxide and its loss on ignition was 0.9 per cent. The purpose was to see if the dark color would obscure the end-point in the ethanol-glycerol methods to any serious degree.

Comment has been made on the inclusion of finished cement in the test of methods. The working committee is aware of the fact that there is no method that differentiates between free calcium oxide and free calcium hydroxide. A lot of clinker and the cement made from it may or may not show the same result in a determination of free lime. If there is a difference in the results and it is consistent for a given mill over a period of time, it may be convenient for a consumer to make his free lime test with cement instead of clinker. From this viewpoint we are interested to know if the test can be made with cement and therefore we have included cement in this investigation.

METHODS

Five methods for the determination of free lime were investigated. They were all the methods which were available in the English language and were believed to possess possibilities for use as A.S.T.M. specification methods. All were various modifications of two fundamental methods, the ethanol-glycerol and the ethylene-glycol method. Since the methods in full detail were a part of our previous progress report,³ it is not necessary to describe them in great detail in this report. However, a brief outline and a few remarks on them may be appropriate here.

Methods Ia, Ib, IIa, IIb, IIIa, and IIIb are modifications of Emley's ethanol-glycerol method. Method Ia is the modification developed by Lerch and Bogue.⁴

NOTE.—The working Committee solicits constructive comments and suggestions on this report. Communications should be sent to the chairman, W. C. Hanna.

¹ A Report of the Working Committee on Methods of Chemical Analysis presented at the meeting of A.S.T.M. Committee C-1 on Cement, June 28, 1938, Atlantic City, N. J.

² W. C. Hanna, Chief Chemist and Chemical Engineer, California Portland Cement Co., G. A. Saeger, Assistant Superintendent and Chief Chemist, Gulf Portland Cement Co., and T. A. Hicks, General Chemist, Universal Atlas Cement Co.

³ Preprint, 1938 Report of Committee C-1 on Cement, p. 7; also 1938 *Proceedings*, Vol. 38, Part I, to be issued in December.

⁴ Wm. Lerch and R. H. Bogue, "Revised Procedure for the Determination of Uncombined Lime in Portland Cement," *Industrial and Engineering Chemistry, Analytical Edition*, Vol. 2, No. 3, July 15, 1930, p. 296.



TABLE I.—DETERMINATIONS OF FREE TIME, Etc.

| Laboratory | SAMPLE N | | | | | | | | | | | | | SAMPLE O | | | | | | | | | | | | | SAMPLE P | | | | | | | |
|------------|------------|------|------------|------|-------------|------|-------------|------|--------------|------|--------------|------|--------|------------|------|------------|------|-------------|------|-------------|------|--------------|------|--------------|------|--------|------------|------|------------|------|-------------|------|--------------|-----|
| | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | Method | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | Method | Method I a | | Method I b | | Method II a | | Method III b | |
| | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | | (1) | (2) | (1) | (2) | (3) | (4) | | |
| 1 | 0.1 | 0.1 | | | 0.3 | 0.3 | | | 0.5 | 0.3 | | | 0.4 | | 1.7 | 1.7 | | | 2.4 | 2.3 | | | 2.2 | 2.2 | | 2.4 | | 0.6 | 0.6 | 0.7 | 0.7 | 1.1 | 1.1 | |
| 2 | | | | | | | | | 0.5 | 0.5 | | | | | | | | | | | | | 1.9 | 1.8 | | | | | | | | | 1.0 | 1.0 |
| 3 | 0.3 | 0.3 | | | 0.3 | 0.4 | | | 0.3 | 0.4 | | | 0.4 | | 2.4 | 2.4 | | | 2.4 | 2.5 | | | 2.5 | 2.5 | | 1.8 | | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | |
| 4 | 0.2 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.3 | 0.4 | 0.2 | 0.2 | 0.4 | 0.4 | 0.6 | | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 2.0 | 2.1 | | 2.5 | 2.3 | | 2.1 | 2.5 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | |
| 5 | 0.3 | 0.3 | 0.2 | 0.2 | 0.9 | 0.8 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.6 | nil | 2.3 | 2.3 | 2.2 | 2.2 | 2.5 | 2.5 | 2.2 | 2.2 | 2.4 | 2.4 | 2.3 | 2.3 | 2.1 | 1.7 | 1.2 | 1.2 | 1.1 | 1.1 | 1.4 | 1.4 |
| 6 | 0.2 | 0.2 | | | 0.3 | 0.3 | | | 0.3 | 0.3 | | | 0.7 | 0.8 | 2.1 | 2.1 | | | 2.2 | 2.3 | | | 2.1 | 2.1 | | 2.9 | 3.0 | 1.5 | 1.5 | 0.6 | 0.6 | 1.6 | 1.6 | |
| 7 | 0.1 | | | nil | 0.1 | | 0.1 | | trace | | | 0.1 | | | 1.3 | | | | 1.1 | | | 1.3 | | 1.0 | | 1.2 | | 0.7 | | 0.6 | | 0.7 | 0.7 | |
| 8 | 0.3 | 0.2 | | | 0.4 | 0.4 | | | 0.4 | 0.4 | | | 0.5 | 0.3 | 2.0 | 2.0 | | | 2.3 | 2.3 | | | 2.2 | 2.2 | | 2.1 | 2.3 | 1.1 | 1.1 | 0.9 | 0.9 | 1.1 | 1.1 | |
| 9 | 0.4 | 0.4 | 0.4 | 0.4 | 0.7 | 0.7 | 0.6 | 0.6 | 0.4 | 0.5 | 0.4 | 0.5 | 0.5 | | 2.5 | | 2.7 | 2.7 | 2.4 | 2.4 | 2.3 | 2.3 | 2.5 | 2.5 | 2.4 | 2.4 | 2.3 | 1.3 | 1.4 | 1.3 | 1.3 | 1.6 | 1.6 | |
| 10 | 0.4 | 0.4 | | 0.1 | 0.4 | 0.4 | | 0.1 | 0.4 | 0.4 | | 0.1 | 0.8 | 0.1 | 2.7 | 2.8 | | 1.8 | 2.7 | 2.7 | | 1.8 | 2.7 | 2.7 | 1.9 | 1.9 | 2.3 | 2.1 | 1.7 | 1.7 | 0.9 | 0.9 | 1.6 | 1.6 |
| 11 | 0.2 | 0.2 | | | 0.5 | 0.5 | | | 0.2 | 0.2 | | | 0.6 | 0.3 | 2.0 | 2.0 | | | 2.3 | 2.3 | | | 2.0 | 2.1 | | 2.5 | 2.6 | 1.2 | 1.2 | 1.0 | 1.0 | 1.1 | 1.1 | |
| 12 | 0.3 | 0.3 | | | 0.3 | 0.3 | | | 0.4 | 0.4 | | | 0.7 | | 2.2 | 2.2 | | | 2.1 | 2.2 | | | 2.2 | 2.2 | | 2.4 | | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | |
| 13 | 0.2 | 0.3 | 0.3 | 0.3 | | 0.4 | 0.3 | 0.3 | | 0.4 | 0.4 | 0.4 | 0.5 | 0.2 | 2.0 | 2.0 | 2.1 | 2.1 | | 2.1 | 1.9 | 1.9 | | 2.2 | 2.2 | 2.2 | 2.1 | 1.1 | 1.1 | 1.1 | 1.1 | | | |
| 14 | 0.3 | 0.3 | | | 0.6 | 0.6 | | | 0.3 | 0.3 | | | 0.4 | 0.6 | 2.5 | 2.5 | | | 2.5 | 2.5 | | | 2.5 | 2.5 | | 2.5 | 2.7 | 1.3 | 1.3 | 1.3 | 1.3 | 1.2 | 1.2 | |
| 15 | 0.2 | 0.2 | | | 0.3 | 0.3 | | | 0.3 | 0.3 | | | 0.5 | | 2.1 | 2.1 | | | 2.3 | 2.3 | | | 2.2 | 2.2 | | 2.3 | | 1.8 | 1.9 | 1.9 | 1.9 | 2.0 | 2.0 | |
| 16 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 | 0.2 | 2.2 | 2.2 | 1.8 | 1.8 | 2.4 | 2.4 | 2.2 | 2.2 | 2.3 | 2.3 | 2.5 | 2.5 | 2.1 | 1.2 | 1.2 | 1.1 | 1.1 | 1.4 | 1.4 | |
| 17 | 0.3 | 0.3 | 0.3 | 0.2 | 0.5 | 0.5 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.3 | 0.6 | 0.2 | 2.1 | 2.0 | 1.8 | 1.7 | 2.2 | 2.2 | 2.0 | 2.2 | 2.2 | 2.2 | 2.0 | 2.0 | 2.2 | 2.2 | 1.2 | 1.1 | 1.0 | 1.0 | 1.2 | 1.2 |
| 18 | nil | | | | 0.4 | | | | 0.1 | | | | 0.6 | 0.3 | 1.7 | | | | 2.7 | | | 1.8 | | | | 2.6 | 2.3 | 0.6 | | 0.3 | | 1.1 | 1.1 | |
| 19 | 0.3 | 0.3 | | | 0.3 | 0.3 | | | 0.4 | 0.4 | | | 0.3 | 0.7 | 2.4 | 2.4 | | | 2.6 | 2.6 | | | 2.4 | 2.4 | | 2.2 | 2.0 | 0.9 | 0.9 | 0.6 | 0.6 | 1.0 | 1.0 | |
| 20 | 0.1 | 0.1 | | | 0.4 | 0.4 | | | 0.4 | 0.3 | | | 0.6 | 0.2 | 2.1 | 2.1 | | | 2.2 | 2.1 | | | 2.1 | 2.1 | | 2.3 | 2.2 | 0.9 | 0.9 | 0.9 | 0.9 | 1.2 | 1.2 | |
| 21 | 0.1 | 0.1 | | | 0.4 | 0.5 | | | 0.3 | 0.3 | | | 0.6 | 0.2 | 1.4 | 1.4 | | | 2.0 | 2.0 | | | 1.6 | 1.6 | | 2.0 | 1.9 | 0.5 | 0.5 | 0.4 | 0.4 | 1.0 | 1.0 | |
| 22 | 0.4 | 0.4 | 0.3 | 0.3 | 1.0 | 1.0 | 0.3 | 0.2 | 0.4 | 0.3 | | | | | 2.4 | 2.4 | 2.4 | 2.4 | 2.7 | 2.7 | 2.3 | 2.3 | 2.3 | 2.3 | | | 1.5 | 1.5 | 1.4 | 1.4 | 1.8 | 1.8 | | |
| 23 | 0.9 | 0.8 | 0.7 | 0.9 | 1.2 | 1.0 | 1.2 | 1.3 | 0.9 | 1.1 | 1.1 | 1.2 | 0.9 | 0.9 | 2.3 | 2.0 | 2.6 | 2.5 | 2.4 | 2.3 | 3.4 | 3.1 | 2.2 | 2.1 | 2.2 | 2.2 | 1.9 | 1.5 | 1.2 | 1.3 | 1.3 | 1.8 | 1.7 | |
| 24 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.5 | 0.6 | 0.5 | 2.3 | 2.4 | 2.3 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.5 | 2.6 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| 25 | 0.2 | 0.3 | | | 0.4 | 0.4 | | | 0.4 | 0.4 | | | 0.7 | 0.7 | 2.3 | 2.3 | | | 2.4 | 2.4 | | | 2.2 | 2.2 | | 2.4 | 2.4 | 1.0 | 1.0 | 1.1 | 1.1 | 1.3 | 1.3 | |
| 26 | 0.1 | 0.1 | | | 0.6 | 0.6 | | | 0.5 | 0.6 | | | 0.6 | 0.3 | 2.1 | 2.1 | | | 2.2 | 2.2 | | | 2.3 | 2.3 | | 2.3 | 2.4 | 1.2 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | |
| 27 | 0.2 | 0.2 | | | 0.3 | 0.3 | | | 0.2 | 0.3 | | | 0.5 | | 2.2 | 2.2 | | | 2.3 | 2.3 | | | 2.2 | 2.2 | | 2.6 | | 1.2 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | |
| 28 | 0.4 | 0.3 | | | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | | | 0.4 | 0.3 | 2.2 | 2.2 | | | 2.0 | 2.0 | 2.0 | 2.0 | 1.8 | 1.8 | | 2.3 | 2.1 | 1.4 | 1.4 | 1.0 | 1.0 | 1.3 | 1.3 | |
| 29 | 0.1 | 0.1 | | | 0.2 | 0.2 | | | 0.3 | 0.3 | | | 0.3 | 0.3 | 2.0 | 2.0 | | | 2.1 | 2.2 | | | 2.0 | 2.0 | | 2.1 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | |
| 30 | 0.2 | 0.3 | | | 0.3 | 0.3 | | | 0.3 | 0.3 | | | 0.5 | nil | 2.0 | 2.1 | | | 2.0 | 2.1 | | | 1.8 | 1.8 | | 2.4 | 1.7 | 0.8 | 0.8 | 1.1 | 1.1 | 0.9 | 0.9 | |
| 31 | 0.2 | 0.2 | 0.2 | 0.2 | 0.8 | 0.8 | 0.6 | 0.6 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | | 1.9 | 1.9 | 1.5 | 1.5 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 | 1.5 | 2.1 | 0.9 | 0.9 | 0.6 | 0.6 | 0.9 | 0.9 | |
| 32 | 0.3 | 0.3 | | | 0.7 | 0.7 | | | 0.6 | 0.6 | 0.4 | 0.4 | | | 2.3 | 2.3 | 2.1 | 2.1 | 2.7 | 2.7 | | | 2.7 | 2.7 | | | 1.3 | 1.3 | 1.0 | 1.0 | 1.6 | 1.6 | | |
| 33 | 0.3 | 0.3 | | | 0.4 | | | | 0.3 | | | | | | 2.1 | | | | 2.3 | | | | 2.0 | | | | | 1.1 | | | | | | |
| 34 | 0.2 | | | | 0.4 | | | | 0.3 | | | | | | 1.9 | | | | 2.3 | | | | 2.0 | | | | | 1.2 | | 1.2 | | | | |
| 35 | 0.1 | 0.2 | | | 0.7 | 0.7 | | | 0.4 | 0.4 | | | 0.2 | | 1.9 | 2.0 | | | 2.2 | 2.2 | | | 2.0 | 2.0 | | | 2.1 | 0.9 | 0.9 | 0.9 | 0.9 | 1.1 | 1.1 | |
| 36 | 0.1 | nil | | | 0.4 | 0.4 | | | 0.3 | 0.3 | | | 0.5 | 0.1 | 2.4 | 2.3 | | | 2.2 | 2.2 | | | 2.0 | 2.0 | | 1.1 | 1.8 | 1.0 | 0.9 | 0.7 | 0.7 | 1.0 | 1.0 | |
| Maximum | 0.9 | 0.8 | 0.7 | 0.9 | 1.2 | 1.0 | 1.2 | 1.3 | 0.9 | 1.1 | 1.1 | 1.2 | 0.9 | 0.9 | 1.7 | 2.8 | 2.6 | 2.5 | 2.7 | 2.7 | 3.4 | 3.1 | 2.7 | 2.7 | 2.5 | 2.5 | 2.9 | 1.8 | 1.9 | 1.9 | 1.9 | 2.0 | 2.0 | |
| Minimum | 0.2 | 0.3 | 0.3 | 0.3 | 0.5 | 0.5 | 0.4 | 0.4 | 0.3 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 2.1 | 2.1 | 2.0 | 2.1 | 2.3 | 2.3 | 2.1 | 2.2 | 2.1 | 2.2 | 2.0 | 2.2 | 2.2 | 1.1 | 1.1 | 1.0 | 1.0 | 1.2 | 1.2 | |
| Mean | 0.11 | 0.10 | 0.10 | 0.14 | 0.16 | 0.14 | 0.19 | 0.21 | 0.11 | 0.11 | 0.17 | 0.19 | 0.12 | 0.18 | 0.20 | 0.18 | 0.31 | 0.24 | 0.22 | 0.16 | 0.36 | 0.25 | 0.21 | 0.17 | 0.30 | 0.21 | 0.24 | 0.20 | 0.25 | 0.20 | 0.21 | 0.19 | 0.18 | |
| P.E.(±) | 0.11 | 0.10 | 0.10 | 0.14 | 0.16 | 0.14 | 0.19 | 0.21 | 0.11 | 0.11 | 0.17 | 0.19 | 0.12 | 0.18 | 0.20 | 0.18 | 0.31 | 0.24 | 0.22 | 0.16 | 0.36 | 0.25 | 0.21 | 0.17 | 0.30 | 0.21 | 0.24 | 0.20 | 0.25 | 0.20 | 0.21 | 0.19 | 0.18 | |

P.E. = The Probable Error of a single observation. P.E. = $\pm 0.674 \sqrt{\frac{\sum d^2}{n-1}}$ where

TABLE II.—TIME REQUIRED FOR D
(Hours and Minute

| | SAMPLE N | | | | | | | | | | | | SAMPLE O | | | | | | | | | | | | SAMPLE P | | | | | | Method II b |
|---------|---------------|------|---------------|------|----------------|-------|----------------|------|-----------------|------|-----------------|------|---------------|------|---------------|------|----------------|-------|----------------|------|-----------------|------|-----------------|------|---------------|-------|---------------|------|----------------|------|----------------|
| | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | Method I a | | Method I b | | Method II a | | |
| | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | |
| | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | |
| Maximum | 7:13 | 8:00 | 6:20 | 6:48 | 12:15 | 13:15 | 7:40 | 7:40 | 5:00 | 5:00 | 3:05 | 4:05 | 9:05 | 9:33 | 8:20 | 9:20 | 10:30 | 11:30 | 4:00 | 4:30 | 5:52 | 6:52 | 4:30 | 4:30 | 10:05 | 11:15 | 7:40 | 9:40 | 7:40 | 7:40 | |
| Minimum | 1:00 | 2:20 | 1:15 | 2:15 | 1:00 | 1:40 | 1:15 | 0:35 | 1:10 | 1:45 | 1:30 | 3:50 | 4:00 | 3:20 | 4:20 | 1:30 | 1:37 | 1:30 | 2:00 | 1:40 | 2:10 | 2:20 | 3:30 | 4:20 | 2:42 | 4:10 | 0:55 | 1:40 | 1:40 | 1:40 | |
| Mean | 4:14 | 4:56 | 4:11 | 4:44 | 3:27 | 3:42 | 2:40 | 2:32 | 2:27 | 2:46 | 2:15 | 2:25 | 6:24 | 7:12 | 5:56 | 6:40 | 3:03 | 3:28 | 2:42 | 2:51 | 3:12 | 3:28 | 3:06 | 3:22 | 6:10 | 6:57 | 5:22 | 6:09 | 2:52 | 3:04 | |

Anhydrous barium chloride is used as an accelerator in Methods IIa and IIb. It was suggested by Brandenburg.⁵

The use of dried sodium chloride as an accelerator as in Methods IIIa and IIIb was suggested by T. A. Hicks of Universal Atlas Cement Co. in a private communication.

The use of U.S.P. or "chemically pure" glycerol containing water up to 5 per cent is allowed in the "a" methods while nearly anhydrous glycerol is required in the "b" methods.

Four different end-points were used in these six methods as follows:

- (1) When the pink color of phenolphthalein does not reappear after one hour of boiling.

- (2) When after two hours of boiling the content of free lime does not increase by more than 0.05 per cent.

- (3) When the pink color of phenolphthalein does not reappear after a half hour of boiling.

- (4) When after an hour of boiling the content of free lime does not increase by more than 0.05 per cent.

The end-points (1) and (2) are for Methods Ia and Ib. It is convenient to use the two end-points on the same portion of sample but they are independent of each other and (2) does not necessarily follow (1) in all cases. The same thing can be said of the end-points (3) and (4) which are used in Methods IIa, IIb, IIIa, and IIIb.

"Boiled glycerol" required for the "b" methods may not be absolutely anhydrous but should be at least nearly so. One laboratory prepared two lots of boiled glycerol and

⁵ H. R. Brandenburg, "A Tentative Modification of the Free Line Method," *Rock Products*, Vol. 34, No. 6, March 14, 1931, p. 68.

| SAMPLE P | | | | | | | | | | SAMPLE Q | | | | | | | | | | SAMPLE R | | | | | | | | | | Laboratory | |
|-------------|-------------|--------------|--------------|------|--------|------|------------|------------|------|-------------|-------------|------|--------------|--------------|------|--------|------------|------------|------|-------------|-------------|------|--------------|--------------|------|--------|------|------|------|------------|----------|
| Method II a | Method II b | Method III a | Method III b | | Method | | Method I a | Method I b | | Method II a | Method II b | | Method III a | Method III b | | Method | Method I a | Method I b | | Method II a | Method II b | | Method III a | Method III b | | Method | | | | | |
| (3) | (4) | (3) | (4) | (3) | (4) | IV | V | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | IV | V | | |
| 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 0.9 | 0.9 | 1.1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.9 | 0.9 | 0.5 | 0.5 | 0.9 | 0.9 | 0.9 | 1 | | |
| 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 | 1.0 | 1.0 | 0.8 | 2 | | |
| 0.9 | 0.9 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.2 | 0.7 | 0.7 | 0.4 | 0.4 | 0.7 | 0.7 | 0.7 | 0.8 | 0.6 | 0.6 | 0.8 | 0.8 | 0.9 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 1.0 | 3 | | |
| 1.4 | 1.4 | 1.1 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.8 | 0.9 | 0.7 | 0.7 | 1.4 | 1.3 | 1.1 | 1.2 | 0.8 | 0.5 | 1.0 | 1.0 | 1.3 | 1.2 | 1.2 | 1.2 | 1.0 | 4 | | |
| 1.6 | 1.6 | 0.9 | 1.4 | 1.4 | 1.0 | 2.1 | 2.0 | 0.5 | 0.5 | 0.2 | 0.2 | 0.6 | 0.6 | 0.3 | 0.3 | 0.7 | 0.7 | 0.4 | 0.4 | 1.0 | 1.0 | 0.7 | 0.7 | 0.9 | 0.9 | 0.8 | 0.9 | 1.4 | 5 | | |
| 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.4 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 1.0 | 0.5 | 0.8 | 0.9 | 0.9 | 0.9 | 0.8 | 0.9 | 0.9 | 0.7 | 6 | | |
| 1.6 | 1.6 | 1.1 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 0.5 | 0.5 | 0.4 | 0.4 | 0.7 | 0.7 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.6 | 0.7 | 0.9 | 0.7 | 0.7 | 1.0 | 1.0 | 0.9 | 0.9 | 1.0 | 7 | | |
| 1.6 | 1.6 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 0.9 | 0.9 | 0.8 | 0.8 | 0.9 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 | 1.1 | 1.1 | 1.3 | 1.3 | 1.1 | 1.0 | 1.1 | 1.0 | 1.0 | 8 | | |
| 1.6 | 1.6 | 0.9 | 1.5 | 1.6 | 0.9 | 0.9 | 1.4 | 0.8 | 0.8 | 0.5 | 0.6 | 0.7 | 0.8 | 0.4 | 0.4 | 0.8 | 0.8 | 0.5 | 0.6 | 1.3 | 1.4 | 0.6 | 0.6 | 1.2 | 1.3 | 0.5 | 0.6 | 0.8 | 9 | | |
| 1.1 | 1.1 | 0.9 | 1.0 | 1.0 | 1.0 | 2.1 | 1.3 | 0.5 | 0.5 | 0.4 | 0.4 | 0.7 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.9 | 0.8 | 0.6 | 0.6 | 0.8 | 0.9 | 0.7 | 0.8 | 1.1 | 1.0 | 1.1 | 10 | | |
| 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 0.7 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.8 | 0.8 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 1.0 | 1.0 | 0.8 | 0.9 | 1.0 | 11 | | |
| 1.1 | 1.1 | 1.0 | 1.1 | 1.1 | 1.2 | 1.2 | 1.3 | 0.7 | 0.7 | 0.8 | 0.7 | 0.7 | 0.8 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0.7 | 0.9 | 0.9 | 0.8 | 0.8 | 1.1 | 0.9 | 0.9 | 1.0 | 1.0 | 12 | | |
| 2.0 | 2.0 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.4 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 1.0 | 1.0 | 1.2 | 13 | | |
| 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 2.0 | 2.1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 | 0.7 | 0.6 | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1.1 | 1.1 | 1.4 | 1.5 | 1.1 | 1.1 | 1.2 | 14 | | |
| 1.4 | 1.4 | 1.4 | 1.3 | 1.3 | 1.5 | 1.5 | 1.1 | 0.7 | 0.7 | 0.6 | 0.6 | 0.9 | 0.9 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.6 | 0.7 | 0.7 | 0.7 | 1.0 | 0.9 | 0.9 | 0.9 | 1.1 | 1.0 | 15 | | |
| 1.1 | 1.1 | 1.1 | 1.3 | 1.2 | 1.1 | 1.1 | 1.1 | 0.6 | 0.6 | 0.5 | 0.5 | 0.8 | 0.7 | 0.6 | 0.6 | 0.8 | 0.8 | 0.7 | 0.6 | 0.9 | 0.9 | 0.5 | 0.6 | 1.0 | 1.0 | 1.0 | 1.0 | 0.8 | 16 | | |
| 1.1 | 1.1 | 0.8 | 0.8 | 0.7 | 0.7 | 1.3 | 1.1 | 0.7 | 0.7 | 0.4 | 0.4 | 0.7 | 0.7 | 0.4 | 0.4 | 0.5 | 0.4 | 0.8 | 0.7 | 0.1 | 0.1 | 1.0 | 1.0 | 0.7 | 0.7 | 0.9 | 0.9 | 1.1 | 17 | | |
| 1.0 | 1.0 | 0.7 | 1.0 | 1.0 | 0.6 | 0.6 | 0.9 | 0.6 | 0.6 | 0.4 | 0.4 | 0.6 | 0.6 | 0.4 | 0.4 | 0.6 | 0.7 | 0.5 | 0.6 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 1.2 | 18 | | |
| 1.0 | 1.0 | 0.7 | 1.0 | 1.0 | 1.0 | 1.4 | 0.9 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.5 | 0.5 | 0.8 | 0.8 | 0.7 | 0.6 | 0.7 | 0.6 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 19 | | |
| 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.4 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.5 | 0.5 | 0.8 | 0.8 | 0.7 | 0.6 | 0.7 | 0.6 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 20 | | |
| 1.8 | 1.8 | 0.8 | 0.7 | 0.7 | 0.7 | 1.0 | 1.0 | 0.3 | 0.3 | 0.4 | 0.4 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 1.1 | 1.0 | 0.3 | 0.2 | 1.0 | 1.0 | 0.9 | 0.9 | 1.1 | 21 | | |
| 1.0 | 1.0 | 1.2 | 1.2 | 1.4 | 1.3 | 1.3 | 1.3 | 1.0 | 0.9 | 0.8 | 0.8 | 1.1 | 0.8 | 0.7 | 0.7 | 0.9 | 0.9 | 0.7 | 0.7 | 1.3 | 1.1 | 1.1 | 1.1 | 1.6 | 1.6 | 1.1 | 1.1 | 1.0 | 22 | | |
| 1.3 | 1.3 | 1.0 | 1.0 | 1.3 | 1.0 | 1.2 | 0.6 | 2.2 | 2.3 | 1.9 | 1.8 | 1.0 | 1.0 | 1.6 | 1.3 | 0.9 | 1.2 | 1.3 | 1.2 | 0.7 | 0.8 | 0.9 | 0.8 | 1.1 | 0.8 | 1.2 | 1.1 | 1.1 | 23 | | |
| 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.5 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.9 | 0.9 | 1.1 | 1.2 | 1.1 | 1.2 | 1.1 | 1.2 | 1.2 | 24 | | |
| 1.3 | 1.3 | 1.1 | 1.1 | 1.2 | 1.3 | 1.2 | 1.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.6 | 0.7 | 0.8 | 1.0 | 1.0 | 0.9 | 1.0 | 1.1 | 1.1 | 25 | | |
| 1.2 | 1.2 | 1.1 | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.6 | 0.6 | 0.8 | 0.8 | 0.9 | 0.8 | 0.8 | 0.8 | 1.2 | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.2 | 26 | | |
| 1.3 | 1.3 | 1.1 | 1.0 | 1.0 | 1.3 | 1.2 | 1.4 | 0.7 | 0.7 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.8 | 0.8 | 0.9 | 0.9 | 0.7 | 0.7 | 1.0 | 1.0 | 1.0 | 1.0 | 0.8 | 0.8 | 1.1 | 27 | | |
| 1.3 | 1.3 | 1.2 | 1.0 | 1.0 | 1.3 | 1.2 | 1.4 | 0.7 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.9 | 0.9 | 1.0 | 1.0 | 0.8 | 0.7 | 1.1 | 28 | | |
| 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 0.9 | 0.5 | 0.5 | 0.6 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 | 0.4 | 0.7 | 0.6 | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 0.6 | 29 | | |
| 0.9 | 0.9 | 1.1 | 0.9 | 0.9 | 1.1 | 1.1 | 0.7 | 0.6 | 0.6 | 0.4 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 1.0 | 0.8 | 0.9 | 0.8 | 0.8 | 0.9 | 0.8 | 0.9 | 0.5 | 0.6 | 30 | | |
| 1.1 | 1.1 | 0.7 | 0.7 | 0.7 | 0.7 | 1.0 | 1.0 | 0.3 | 0.2 | 0.2 | 0.2 | 0.5 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.4 | 0.4 | 0.7 | 0.6 | 0.6 | 0.4 | 0.4 | 0.8 | 0.8 | 0.8 | 0.4 | 31 | | |
| 0.9 | 0.9 | 1.0 | 1.0 | 1.4 | 1.3 | 1.3 | 1.3 | 0.8 | 0.8 | 0.6 | 0.6 | 0.9 | 0.9 | 0.6 | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 1.2 | 1.2 | 1.3 | 1.3 | 0.6 | 0.6 | 0.9 | 32 | | |
| 1.6 | 1.6 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.5 | 0.5 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 1.0 | 1.0 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 33 | | |
| 1.4 | 1.4 | 1.3 | 1.3 | 1.4 | 1.4 | 1.4 | 1.4 | 0.5 | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 34 | | |
| 1.2 | 1.2 | 1.0 | 1.0 | 1.3 | 1.3 | 1.3 | 1.0 | 0.5 | 0.5 | 0.2 | 0.2 | 0.6 | 0.6 | 0.4 | 0.5 | 0.8 | 0.8 | 0.4 | 0.4 | 0.6 | 0.6 | 0.9 | 0.9 | 0.7 | 0.7 | 1.1 | 1.2 | 0.9 | 35 | | |
| 1.0 | 1.0 | 1.1 | 1.5 | 1.4 | 1.0 | 1.0 | 0.7 | 0.8 | 0.8 | 0.4 | 0.4 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.4 | 0.3 | 0.1 | 0.1 | 0.8 | 0.8 | 0.8 | 0.8 | 0.6 | 0.6 | 0.5 | 36 | |
| 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 1.9 | 1.8 | 1.1 | 0.9 | 1.6 | 1.3 | 1.4 | 1.3 | 1.3 | 1.2 | 1.1 | 1.0 | 1.3 | 1.4 | 1.3 | 1.3 | 1.6 | 1.6 | 1.2 | 1.4 | Maximum | |
| 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.7 | 0.6 | 0.5 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.1 | 0.1 | 0.4 | 0.4 | 0.7 | 0.7 | 0.5 | 0.6 | Minimum | |
| 1.9 | 1.9 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 0.2 | 0.2 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.7 | 0.8 | 0.7 | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.5 | Mean |
| 0.19 | 0.19 | 0.16 | 0.18 | 0.17 | 0.18 | 0.19 | 0.23 | 0.23 | 0.22 | 0.23 | 0.20 | 0.19 | 0.09 | 0.13 | 0.15 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 | 0.11 | 0.17 | 0.17 | 0.18 | 0.19 | 0.20 | 0.13 | 0.13 | 0.12 | 0.11 | P. E.(±) |

where Σd^2 is the sum of the squares of the deviations and n is the number of observations.

FOR DETERMINATIONS
(Minutes)

| Method II a | | SAMPLE P | | | | | | SAMPLE Q | | | | | | | | | | | | SAMPLE R | | | | | | | | | | | | Average for all Samples | |
|-------------|------|-------------|------|--------------|------|--------------|------|------------|-------|------------|------|-------------|------|-------------|------|--------------|------|--------------|------|------------|-------|------------|------|-------------|------|-------------|------|--------------|------|--------------|------|-------------------------|------|
| | | Method II b | | Method III a | | Method III b | | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | Method I a | | Method I b | | Method II a | | Method II b | | Method III a | | Method III b | | | |
| | | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | IV | V |
| 4:40 | 7:40 | 6:50 | 4:20 | 5:18 | 5:48 | 6:42 | 7:42 | 11:50 | 13:50 | 7:38 | 9:08 | 7:50 | 6:27 | 6:50 | 4:20 | 10:20 | 9:03 | 6:55 | 5:48 | 23:30 | 25:30 | 8:30 | 9:30 | 7:42 | 8:00 | 3:30 | 4:00 | 5:57 | 6:57 | 4:00 | 4:27 | 2:00 | 1:30 |
| 5:55 | 1:40 | 1:15 | 1:20 | 1:20 | 1:35 | 1:35 | 2:05 | 1:30 | 3:55 | 1:30 | 2:30 | 0:45 | 1:05 | 0:30 | 1:07 | 1:30 | 1:53 | 1:00 | 1:45 | 2:00 | 3:05 | 2:15 | 3:15 | 1:00 | 1:30 | 1:30 | 2:00 | 1:50 | 2:07 | 1:45 | 2:10 | 0:30 | 0:30 |
| 5:52 | 2:39 | 2:34 | 2:44 | 2:56 | 3:11 | 2:49 | 3:06 | 5:47 | 6:44 | 4:45 | 5:24 | 2:38 | 2:43 | 2:15 | 2:23 | 3:09 | 3:22 | 2:40 | 2:57 | 6:29 | 7:26 | 5:43 | 6:25 | 2:53 | 3:11 | 2:40 | 2:49 | 3:14 | 3:37 | 2:42 | 3:04 | 0:54 | 0:51 |

TABLE III.—SUMMARY OF MEANS AND PROBABLE ERRORS

| Sample | MEANS | | | | | | | | | | | | | | PROBABLE ERRORS | | | | | | | | | | | | | |
|---------------------|-------|-----|-----|-----|------|-----|------|-----|-------|-----|-------|-----|-----|-----|-----------------|------|------|------|------|------|------|------|-------|------|-------|------|------|------|
| | I a | | I b | | II a | | II b | | III a | | III b | | IV | V | I a | | I b | | II a | | II b | | III a | | III b | | IV | V |
| | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | | | (1) | (2) | (1) | (2) | (3) | (4) | (3) | (4) | (3) | (4) | (3) | (4) | | |
| N | 0.2 | 0.3 | 0.3 | 0.3 | 0.5 | 0.5 | 0.4 | 0.4 | 0.3 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.11 | 0.10 | 0.10 | 0.14 | 0.16 | 0.14 | 0.19 | 0.21 | 0.11 | 0.11 | 0.17 | 0.19 | 0.12 | 0.18 |
| O | 2.1 | 2.1 | 2.0 | 2.1 | 2.3 | 2.3 | 2.1 | 2.2 | 2.1 | 2.2 | 2.0 | 2.2 | 2.2 | 2.2 | 0.20 | 0.18 | 0.31 | 0.24 | 0.22 | 0.16 | 0.36 | 0.25 | 0.21 | 0.17 | 0.30 | 0.21 | 0.24 | 0.25 |
| P | 1.1 | 1.1 | 1.0 | 1.0 | 1.2 | 1.3 | 1.1 | 1.1 | 1.1 | 1.2 | 1.1 | 1.2 | 1.1 | 1.1 | 0.20 | 0.21 | 0.21 | 0.20 | 0.19 | 0.18 | 0.17 | 0.16 | 0.18 | 0.17 | 0.18 | 0.19 | 0.23 | 0.23 |
| Q | 0.6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.7 | 0.8 | 0.7 | 0.7 | 0.8 | 0.7 | 0.22 | 0.23 | 0.20 | 0.19 | 0.09 | 0.13 | 0.15 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 | 0.11 | 0.17 |
| R | 0.8 | 0.8 | 0.8 | 0.8 | 1.0 | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 0.17 | 0.18 | 0.19 | 0.20 | 0.13 | 0.13 | 0.12 | 0.11 | 0.16 | 0.16 | 0.12 | 0.14 | 0.14 | 0.17 |
| Average for all | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.2 | 1.0 | 1.1 | 1.0 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 | 0.18 | 0.18 | 0.20 | 0.19 | 0.16 | 0.14 | 0.20 | 0.17 | 0.16 | 0.15 | 0.18 | 0.17 | 0.17 | 0.20 |
| Average for P and Q | 0.9 | 0.9 | 0.8 | 0.8 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 1.0 | 0.9 | 0.9 | 1.0 | 0.9 | 0.21 | 0.22 | 0.21 | 0.20 | 0.15 | 0.16 | 0.16 | 0.14 | 0.16 | 0.16 | 0.16 | 0.17 | 0.17 | 0.20 |

RESULTS

Results received from 36 laboratories are given in Tables I and II. One additional laboratory reported tests too late for inclusion in the tables. Table I shows determinations of free lime. The maximum, minimum, mean, and probable error for each method with each sample is shown.

Table II, which is condensed from the original table, shows for each method with each sample, the mean time required, with maximum and minimum values also given. Time is expressed in hours and minutes.

The means and probable errors in Table I are summarized in Table III and an average of means and one of probable errors are calculated for each method. There are two sets of averages, one referring to all samples and the other to only Samples P and Q. The reason for having these two sets is that data are more complete for Samples P and Q than for the other samples and the effect of inconsistent results on the mean and probable error increases as the number of determinations decreases.

COMMENTS

The cooperating laboratories were requested to indicate their preference for an A.S.T.M. method, to give reasons for it, to suggest improvements and to give criticisms of any kind. Their comments vary widely in both nature and quantity. As it is out of the question to present them in full, an attempt has been made to tabulate and abstract them in such a way that a person may be able to make an interpretation of the data and opinions with a minimum of time and effort.

(Editor's Note.—The abstracts of the comments, prepared as an appendix, are not included at this time. Members interested should communicate with Committee C-1 on Cement.)

Preferences for an A.S.T.M. method, reasons for such, preferred end-points, and opinions on boiled glycerol and letting a determination (in the ethanol-glycerol methods) to stand overnight are indicated in Table IV.

Many of the comments were given in such a way that it was difficult to decide how they could fit in the table. The abstraction also had its difficulties. Doubtless there will be disagreement with our interpretation of certain comments. However, we feel that the table and appendix give a good

picture of the general opinion of cement chemists in regard to the various methods for the determination of free lime in portland cement and clinker.

SPECIAL TESTS

The cooperating laboratories were requested to make special tests that were believed to be of interest and to have a bearing on the problem of the determination of free lime. Important contributions to information concerning the problem were made by L. M. Lea, Director of Building Research Station; F. V. Reagel, Engineer of Materials, Missouri State Highway Commission; Roy N. Young, Chemical Engineer, Lehigh Portland Cement Co., and others.

CONCLUSIONS

The average values for the five samples are as follows:

| Sample | Methods Included in Calculation | Free Lime | Probable Error |
|---|---------------------------------|-----------|----------------|
| N (ground clinker) | Ia, IIa, IIIa, IV, V | 0.4 | 0.13 |
| O " | Ia, IIa, IIIa, IV, V | 2.2 | 0.20 |
| P Clinker ground | Ia, IIa, IIIa, IV, V | 1.2 | 0.20 |
| P by laboratories | All methods | 1.1 | 0.19 |
| Q Aged | Ia, IIa, IIIa, IV, V | 0.7 | 0.15 |
| Q cement | All methods | 0.7 | 0.15 |
| R (dark cement) | Ia, IIa, IIIa, IV, V | 0.9 | 0.16 |
| P (calculated as 54 per cent N and 46 per cent O) | | 1.2 | 0.16 |

The determinations in Samples N, O, and R by Methods Ib, IIb, and IIIb are not included in this table as they are insufficient in number for the purpose of comparison from the viewpoints as set out below.

It is interesting to note that the average value actually obtained for Sample P is exactly what is calculated from the values for Samples N and O. The actual probable error (0.20) is a little higher than the calculated value (0.16) but it is to be noted that there is a large amount of variation for any sample or method.

From a study of the data in Tables I and II and the average values given above, it seems to be tenable to conclude that (1) the distribution of Sample P by the committee and its preparation by the laboratories did not introduce a very large error and (2) the determination of free lime may be expected to be as precise in aged and fresh cement as in fresh clinker.

TABLE IV.—PREFERENCES

| Preference based on accuracy or precision | | | | | | | | Preference based on speed or convenience | | | | | | | | Preferred Endpoint | | Opinion on boiled Glycerol | | | Effect of standing overnight | | |
|---|-----|------|------|-------|-------|----|---|--|-----|------|------|-------|-------|----|---|--------------------|------------|----------------------------|---|----|------------------------------|---|-----|
| I a | I b | II a | II b | III a | III b | IV | V | I a | I b | II a | II b | III a | III b | IV | V | (1) or (3) | (2) or (4) | R | O | N' | H | L | N'' |
| 6 | 1 | 5 | 0 | 1 | 2 | 7 | 3 | 0 | 0 | 9 | 2 | 5 | 1 | 7 | 2 | 1 | 5 | 5 | 2 | 10 | 0 | 2 | 3 |

R = recommended; O = objectionable; N' = no advantage seen.
H = high results; L = low results; N'' = no or very little effect



From the following average values for Sample R:

| Methods Included in Calculation | Probable Error |
|------------------------------------|-------------------|
| Ia, IIa, IIIa | 0.16 |
| IV, V | 0.16 |

it appears that while the dark color makes the end-point in the ethanol-glycerol methods more difficult to see, it is not an actual source of error.

It should be pointed out that while the data show, with the understanding that there is no differentiation between free calcium oxide and free calcium hydroxide, that a determination of free lime can be made in cement, they have no bearing on the question concerning the effect of aging or grinding with gypsum on the free lime content in clinker. The original content of free lime in the clinkers of Samples Q and R is not known.

In regard to the recommendation of a method for adoption as an A.S.T.M. tentative method for the determination of free lime in portland cement and clinker, the Working Committee is not prepared to make a recommendation at this time. When the data and comments were tabulated and classified, it became apparent to the Working Committee that it was impossible to give them adequate study and make recommendations at this time. Table IV by itself is far from being an adequate guide for the formation of recommendations. No single method is favored by a majority of the laboratories. A method that seems to have a good following may also have strenuous opposition from a large group. The preferences should be considered with an analysis of the reasons.

The study of the data and comments will require some time and we hope to be assisted by members of Committee C-1 and the cooperating laboratories and all other interested parties in the selection of the best method (or possibly two methods). We will be glad to receive their advice at an early date. We hope to submit a final report with recommendations at the next meeting of Committee C-1 in the fall.

COOPERATING LABORATORIES

Recognizing the widespread interest in the determination of free lime, we sought to offer the opportunity of participation to all who we thought might be interested and might wish to assist in the work. We also realized the tremendous amount of time and expense involved and so we did not require the participants to do all the tests. We were gratified to have assistance from men in both Canada and England as well as the United States. As the work progressed, unforeseen difficulties arose in many laboratories. Some had to withdraw from the work and some others had to curtail their work and make partial reports.

Thirty-seven laboratories made reports. Their names and those of persons, who assisted in various ways, are as follows:

Ash Grove Lime and Portland Cement Co., Guy O. Gardner, Superintendent.
Building Research Station (England), F. M. Lea, Director of Building Research.
Bureau of Reclamation, R. F. Walter, Chief Engineer.
California Portland Cement Co., O. D. Guire, Jr., Analyst.
Canada Cement Co., Ltd., A. G. Fleming, Chief Chemist, L. E. Shipley, Operating Chemist.
Cowell Portland Cement Co., H. R. Brandenburg, Chief Chemist.
Cowham System Plants, S. Rordam, Director of Research, J. C. Gray, Analyst.

Dewey Portland Cement Co., R. A. Loveland, Research Engineer.
The Federal Portland Cement Co., Inc., J. F. Barton, Chief Chemist.
Gulf Portland Cement Co., G. A. Saeger, Chief Chemist.
Hawkeye Portland Cement Co., J. V. Mandia, Chief Chemist.
Huron Portland Cement Co., W. Marshall Smith, Chief Chemist, A. F. Finadt.
Idaho Portland Cement Co., W. R. Chandler, Chief Chemist.
Lehigh Portland Cement Co., Roy N. Young, Chemical Engineer.
Lone Star Cement Corp. (Kansas), J. A. Fairchild, Chief Chemist, J. H. Griffith.
Louisville Cement Co., E. J. Wechter, Director of Research.
Medusa Portland Cement Co., Harry L. Vanderwerp.
Missouri State Highway Commission, F. V. Reagel, Engineer of Materials.
National Bureau of Standards, L. J. Briggs, Director, P. H. Bates, L. S. Wells, E. P. Flint, M. D. Burdick.
Nazareth Cement Co., J. Clifford Evans, Chief Chemist, E. C. Morgan, J. H. Reichenbach.
North American Cement Corp., H. F. Kichline, Chief Chemist.
Oklahoma Portland Cement Co., O. A. Bayless, Chemical Engineer.
Pacific Portland Cement Co., E. F. Bollinger, Chief Chemist.
Pennsylvania-Dixie Cement Corp., Lester C. Hawk, Chief Chemist.
Petoskey Portland Cement Co., C. L. Phillips, Chief Chemist.
Portland Cement Association, H. F. Gonnerman, Manager of Laboratory.
Riverside Cement Co., Thomas F. Mullan, Chief Chemist.
San Antonio Portland Cement Co., C. L. Lundy, Chief Chemist.
St. Mary's Cement Co., Ltd., A. G. Larsson, Chief Chemist, R. Grosch.
Southwestern Portland Cement Co. (Ohio), J. B. Alexander, Chief Chemist.
Superior Cement Corp. (Ohio), L. I. Loghry, Chief Chemist.
Trinity Portland Cement Co. (Dallas), H. F. Linn, Chief Chemist.
Universal Atlas Cement Co., J. C. Witt, Chemical Engineer, D. I. Elder, Chief Chemist, R. V. Andes.
University of California, R. E. Davis, Consulting Engineer, G. E. Troxell, Professor of Civil Engineering.
Valley Forge Cement Co., M. D. Olver, Supervising Chemist.
Volunteer Portland Cement Co., D. W. Yike, Chief Chemist.
The Whitehall Cement Manufacturing Co., M. H. Meighan, Chief Chemist.

This list does not correspond to the order of laboratories given in the tables.

SUMMARY

We have presented results of the study on five samples by five methods and three extra deviations from them submitted by 37 laboratories in several countries. These data have been considered but no recommendation is made at this time as to the adoption of a tentative method as the Working Committee feels that all of those cooperating and others should have an opportunity to study the problem again with the committee with the complete data before them.

ACKNOWLEDGEMENT

The thanks of the A.S.T.M. and the working committee are due each and every one of those who have generously assisted in the investigation of methods for free lime. We appreciate the generosity of California Portland Cement Co. and Universal Atlas Cement Co. in making it possible for members of their technical staffs to devote a large part of their time to this work.

Respectfully submitted on behalf of the Working Committee,

W. C. HANNA,
Chairman.

Members: T. A. HICKS
G. A. SAEGER



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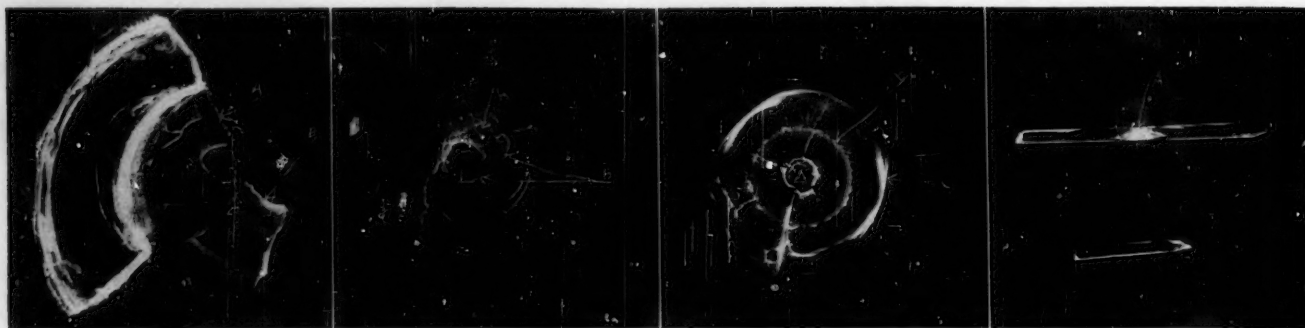


Fig. 1

Fig. 2

Fig. 3

Fig. 4

Photographs of Broken Glass

AMONG the interesting photographs displayed during the Photographic Exhibit at the 1938 Annual Meeting were some submitted by Mr. E. L. Hettinger, Optical Research Dept., Willson Products, Inc., Reading, Pa. Mr. Hettinger's entries won for him honorable mention. Because of the uniqueness of the method he uses in photographing broken glass, he has on request submitted a series of photographs somewhat similar to those displayed at the exhibit.

The accompanying photographs were taken to refute statements that curved glass always breaks outward. In Figure 1, segment *A* shows that some of the glass broke outward, but on segment *B* some broke inward. This varies, depending on the force of the velocity and the hardness of the projectile striking the glass. Figure 2 shows the results of a steel ball blown from a 24 in. blow pipe striking a piece of flat glass with parallel surfaces about 3.5 mm. thick, and at point *A*, the glass fracture was outward. Figure 3 shows at point *A* the contact of the ball, the vibration of the glass stopped at the circle *B*, and then vibrated until the button let go at the outer surface at point *C*. Figure 4 shows a contact made by the steel ball at point *A* resulting in a conical fracture developed as shown in Figure 3.

None of these photographs were made in the usual manner. Instead of making an exposure and developing the film, these were placed in a projector or enlarger and then focused sharply. The broken glass acted as a negative. This is an unusual procedure, but it answered the purpose in a more satisfactory manner than by following the customary methods.

Foreign Standards Recently Issued

Standards issued by a number of engineering and technical organizations in foreign countries are received by the Society as they are adopted. Since members of the Society may be interested in knowing that such standards are available they will be listed in the ASTM BULLETIN.

Recently the following standards have been issued:

BRITISH STANDARD SPECIFICATIONS FOR:

- Ampoules (No. 795—1938).
- Cast Iron Pipes (Vertically Cast) for Water, Gas and Sewage and Special Castings for Use Therewith (No. 78—1938).
- Ferrous Pipes and Piping Installations for and in Connection with Land Boilers (No. 806—1938).
- Brunswick or Chrome Greens (Pure and Reduced) for Paints (No. 303—1938).
- Green Oxide of Chromium for Paints (No. 318—1938).
- Prussian Blue for Paints (No. 283—1938).
- Ultramarine Blue for Paints (No. 314—1938).
- Vermilion and Red Pigment for Paints: Vermilion for Paints (No. 320—1938).
- Red Pigment (Red Lakes, Toner or Pigment Dyestuff) for Paints (No. 333—1938).

BRITISH STANDARD METHOD FOR:

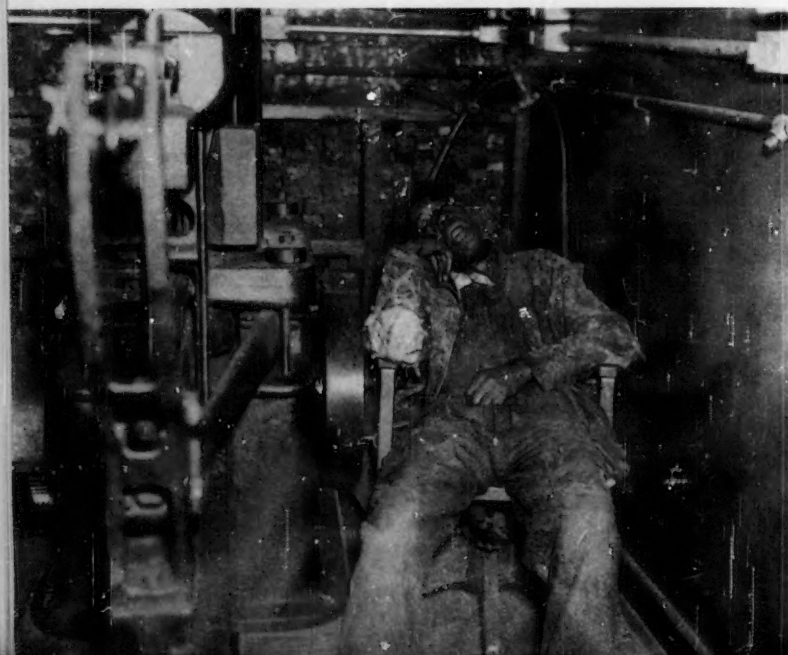
- Crucible Swelling Test for Coal (No. 804—1938).

CANADIAN ENGINEERING STANDARDS ASSOCIATION SPECIFICATIONS FOR:

- Construction and Test of Rigid Steel Conduit (45—1938).
- Construction and Test of Electric Air-Heaters (46—1938).
- Welded Steel Buildings Welding by the Metallic Arc Process. Tentative Welding Qualification Code for Fabricators, Contractors, Supervisors and Welders (S 47 T—1938).
- Reinforcing Materials for Concrete:
 - Billet-Steel Concrete Reinforcing Bars (G 30—1938).
 - Rail-Steel Concrete Reinforcing Bars (G 31—1938).
 - Cold-Drawn Steel Wire for Concrete Reinforcement (G 32—1938).
 - Fabricated Steel Bar or Rod Mats for Concrete Reinforcement (G 45—1938).
 - Welded Steel Wire Fabric for Concrete Reinforcement (G 46—1938).
- Construction and Test of Non-Metallic Sheathed Cable (No. 48—1938).

"Fatigue Testing in Dixie"

A photograph by E. M. Welchel, Metallographic Dept., American Cast Iron Pipe Co., Birmingham, Alabama, displayed in the 1938 Photographic Exhibit.



New Committee Officers Elected

As a result of elections of officers of committees which occur in the even-numbered years, a number of new officers have been chosen to direct the work of the various committees. The list which follows gives the newly elected officers; in all other cases the former officers were honored by reelection.

With no intention of being at all facetious, we refer to the quotation of Dr. C. B. Dudley which appears on this page. Doctor Dudley's statement, defining a complete workable specification for material, includes one word which all committee officers and committee members can probably appreciate. That word is "work." In it is embodied the basic reason for progress that has been and is continuing to be made in the Society's standardization and research activities. To the officers of A.S.T.M. committees, and their closely cooperating members, must go the credit for carrying on this work.

- COMMITTEE A-1 ON STEEL—*Chairman*, N. L. Mochel, Westinghouse Electric and Manufacturing Co., Philadelphia, Pa.; *Vice-Chairman*, W. M. Barr, Union Pacific Railroad Co., Omaha, Neb.
- COMMITTEE A-2 ON WROUGHT IRON—*Chairman*, C. B. Bryant, Southern Railway System, Alexandria, Va.; *Secretary*, W. C. Masters, Flannery Bolt Co., Bridgeville, Pa.
- COMMITTEE A-3 ON CAST IRON—*Vice-Chairman*, Robert Job, Milton Hersey Co., Ltd., Montreal, P. Q., Canada.
- COMMITTEE A-5 ON CORROSION OF IRON AND STEEL—*Chairman*, W. H. Finkeldey, Singmaster & Breyer, New York City; *Second Vice-Chairman*, L. W. Hopkins, American Chain and Cable Co., Inc., Bridgeport, Conn.
- COMMITTEE A-9 ON FERRO-ALLOYS—*Vice-Chairman*, J. H. Critchett, Electro-Metallurgical Co., New York City; *Secretary*, C. M. Loeb, Jr., Climax Molybdenum Co., New York City.
- COMMITTEE A-10 ON IRON-CHROMIUM, IRON-CHROMIUM-NICKEL AND RELATED ALLOYS—*Vice-Chairman*, H. L. Maxwell, E. I. du Pont de Nemours and Co., Inc., Technical Library, Wilmington, Del.
- COMMITTEE B-1 ON COPPER AND COPPER ALLOY WIRES FOR ELECTRICAL CONDUCTORS—*Chairman*, J. H. Foote, The Commonwealth and Southern Corp., Jackson, Mich.; *Secretary*, G. E. Dean, Public Service Electric and Gas Co., Newark, N. J.
- COMMITTEE B-5 ON COPPER AND COPPER ALLOYS, CAST AND WROUGHT—*First Vice-Chairman*, J. W. Bolton, The Lunkenheimer Co., Cincinnati, Ohio; *Second Vice-Chairman*, H. H. Stout, Jr., Phelps Dodge Copper Products Corp., American Copper Products Division, Elizabeth, N. J.
- COMMITTEE B-6 ON DIE-CAST METALS AND ALLOYS—*Vice-Chairman*, J. C. Fox, Doehler Die Casting Co., Toledo, Ohio; *Secretary*, G. L. Werley, The New Jersey Zinc Co., Palmerton, Pa.
- COMMITTEE B-7 ON LIGHT METALS AND ALLOYS, CAST AND WROUGHT—*Secretary*, H. J. Rowe, Aluminum Company of America, Cleveland, Ohio; *Vice-Chairman*, J. A. Gann, The Dow Chemical Co., Midland, Mich.
- COMMITTEE C-1 ON CEMENT—*Vice-Chairman*, D. Wolochow, National Research Council of Canada, Ottawa, Ont., Canada.
- COMMITTEE C-4 ON CLAY PIPE—*Vice-Chairman*, J. C. Riedel, Board of Estimate and Apportionment, New York City.
- COMMITTEE C-5 ON FIRE TESTS OF MATERIALS AND CONSTRUCTION—*Secretary*, H. M. Robinson, Underwriters' Laboratories, Inc., Chicago, Ill.
- COMMITTEE C-7 ON LIME—*Secretary*, John W. Stockett, Jr., National Lime Assn., Washington, D. C.
- COMMITTEE C-9 ON CONCRETE AND CONCRETE AGGREGATES—*Chairman*, F. H. Jackson, U. S. Bureau of Public Roads, Washington, D. C.; *Vice-Chairman*, F. E. Richart, University of Illinois, Urbana, Ill.
- COMMITTEE C-11 ON GYPSUM—*Chairman*, L. S. Wells, National Bureau of Standards, Washington, D. C.
- COMMITTEE C-13 ON CONCRETE PIPE—*Chairman*, Theodore Doll, Structural Engineer, Chicago, Ill.
- COMMITTEE C-14 ON GLASS AND GLASS PRODUCTS—*Vice-Chairman*, U. E. Bowes, Owens-Illinois Glass Co., Toledo, Ohio.
- COMMITTEE C-18 ON NATURAL BUILDING STONES AND SLATE—*Chairman*, T. I. Coe, Structural Service Dept., American Institute of Architects, Washington, D. C.; *Vice-Chairman*, W. C. Clark, Procurement Division, Treasury Dept., Washington, D. C.
- COMMITTEE D-1 ON PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS—*Chairman*, H. E. Smith, Materials Engineer, White Plains, N. Y.
- COMMITTEE D-4 ON ROAD AND PAVING MATERIALS—*Chairman*, E. F. Kelley, U. S. Bureau of Public Roads, Washington, D. C.; *First Vice-*

Chairman, J. E. Myers, New York State Department of Public Works, Albany, N. Y.

COMMITTEE D-8 ON BITUMINOUS WATERPROOFING AND ROOFING MATERIALS—*Vice-Chairman*, E. H. Berger, Consulting Chemist, New York City.

COMMITTEE D-13 ON TEXTILE MATERIALS—*Second Vice-Chairman*, F. S. Mapes, General Electric Co., Schenectady, N. Y.

COMMITTEE E-2 ON SPECTROGRAPHIC ANALYSIS—*Secretary*, B. F. Scribner, National Bureau of Standards, Washington, D. C.

COMMITTEE E-4 ON METALLOGRAPHY—*Chairman*, L. L. Wyman, General Electric Co., Schenectady, N. Y.

Extensive Volume on Creep Data Published

UNDER the auspices of the Joint Committee on Effect of Temperature on the Properties of Metals, there has recently been issued as a joint publication of the A.S.T.M. and A.S.M.E. a volume on creep data comprising some 862 pages of information and data as developed by the Joint Committee with the cooperation of a large number of technologists in leading American and certain foreign institutions who are concerned with problems of materials at high temperatures. The volume is divided into three major sections: wrought steels and ferrous alloys, cast steels and ferrous alloys, and non-ferrous materials. Each of these sections is further subdivided into the individual types, with the first section consisting of twenty-four subdivisions, the second of nine, and the third of four.

Each subdivision consists of tables, describing the steels considered, of individual logarithmic charts of stress and corresponding creep rate for each type of material at each temperature, of a plotting of temperature *versus* creep rate (0.10 per cent per 1000 hr., and in a few cases, 0.01 per cent per 1000 hr.) for each type of material whenever sufficient data were available, and of the standard tabulated forms which were prepared either by the various cooperating laboratories or from the data which they submitted.

It is believed this publication will be of considerable service to a large number of individuals and companies who are interested in the design, construction and use of metals at intermediate and higher temperatures. Copies of the volume in heavy cloth binding (page size 8½ by 11 in.) can be obtained from A.S.T.M. Headquarters at \$12 per copy, United States and Canada; \$14 elsewhere; postage prepaid.

A complete workable specification for material represents a very high order of work. It should combine within itself the harmonized antagonistic interests of both the producer and the consumer, it should have the fewest possible requirements consistent with securing satisfactory material, should be so comprehensive as to leave no chance for ambiguity or doubt, and above all should embody within itself the results of the latest and best studies of the properties of the materials which it covers.

Dr. Charles B. Dudley.

Chemist, Pennsylvania Railroad, 1875-1909; President, American Society for Testing Materials, 1902-1909; Tireless Searcher for the Truth; Pioneering Leader in the Development of Satisfactory Basis of Agreement between Producer and Consumer.



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PERSONALS News items concerning the activities of our members will be welcomed for inclusion in this column.

J. G. MILLER is now Research Chemist, The Barrett Co., Edgewater, N. J.

F. L. PLUMMER, formerly Professor of Structural Engineering, Case School of Applied Science, Cleveland, Ohio, is now Chief Design Engineer, Cuyahoga County Bridge Dept., Cleveland.

INGE LYSE has resigned from Lehigh University where he was Research Professor of Engineering Materials, and has accepted the position of Professor of Reinforced Concrete and Solid Bridges, Norway Institute of Technology, Trondheim, Norway.

M. B. MOORE is now Instructor in Mechanical Technology, Pratt Institute, Brooklyn, N. Y.

F. B. RIGGAN, who was Metallurgist, Stockham Pipe & Fittings Co., Birmingham, Ala., is now Metallurgist, Key Co., St. Louis, Ill.

L. P. SHROPSHIRE is connected with the Asphalt Process Corp., as Vice-President and Manager of the Service Division, New York City.

S. H. MORGAN, formerly Chief Chemist, Shell Petroleum Corp., Arkansas City, Kans., is now Process Engineer, Derby Oil Co., Wichita, Kans.

H. S. BRIGHTLY is Associate Architectural Engineer, Construction Division, Quartermaster General's Office, U. S. War Dept., Washington, D. C. He was formerly Director, Technical and Field Service Division, Indiana Limestone Institute, Bloomington, Ind.

A. R. DIMOCK, JR., is connected with the Southern States Power Co., as Junior Civil Engineer.

A. E. DUNSTAN, Chief Chemist, Anglo-Iranian Oil Co., Ltd., London, England, was recently awarded the Redwood Medal of the Institution of Petroleum Technologists in recognition of his distinguished services to the science and technology of petroleum.

W. M. PHILLIPS, Engineer of Finishing, General Motors Corp., has been elected President of the American Electro-Platers' Society for the year 1938-1939. He is very active in the work of the joint A.E.S.-A.S.T.M. Committee on electroplating.

C. F. SPEH, formerly Senior Technologist, Naval Stores Research Division, Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C., was recently made Principal Chemist, in charge of the Naval Stores Research Division, succeeding Dr. F. P. Veitch, whose retirement was recently announced.

L. E. KERN, formerly Specification Writer, Housing Division, Public Works Administration, Washington, D. C., is now Examining Engineer, Public Works Administration, Washington.

L. C. BIBBER, Welding Engineer, Carnegie-Illinois Steel Corp., Pittsburgh, Pa., has been elected chairman of the Pittsburgh Section, American Welding Society. R. B. LINCOLN, Engineer of Tests, Pittsburgh Testing Laboratory, Pittsburgh, was elected a member of the Executive Committee.

W. B. KOUWENHOVEN has been appointed Dean of the School of Engineering, Johns Hopkins University. He was formerly Professor of Electrical Engineering, Johns Hopkins.

S. S. FRITTS is now Physical Chemist and Testing Engineer, Lone Star Cement Corp., New York City.

A. N. VANDERLIP, formerly Engineer, Metcalf & Metcalf, General Contractors, Inc., Ithaca, N. Y., is now Assistant Professor, College of Engineering, Connecticut State College, Storrs, Conn.

G. E. VEATCH is connected with the J. W. Mortell Co., Kankakee, Ill., as Chemist.

HEWITT WILSON, Professor of Ceramic Engineering, University of Washington, Seattle, is on leave of absence and is Supervising Engineer, Electro-Technical Laboratory, U. S. Bureau of Mines, Norris, Tenn.

L. H. SEABRIGHT is now Chemical Engineer, Michigan Bumper Corp., Grand Rapids, Mich.

FRED SANDBERG, JR., is connected with E. W. Saybolt and Co., Corpus Christi, Tex., as Oil Inspector.

A. R. CURTIS, who was Junior Chemist, Massachusetts Department of Public Works, is now Sales Engineer, Asphalt Dept., Colonial Beacon Oil Co., Inc., Everett, Mass.

W. R. FULLER has become Technical Director, the Marietta Paint and Color Co., Marietta, Ohio. He was Manager of Industrial Research, Devoe & Reynolds Co., Inc., Louisville, Ky.



J. M. Darke



L. F. Rader

L. F. RADER, Associate Professor of Civil Engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., was awarded the Prize of Belgium in a world-wide competition sponsored by the Permanent International Association of Road Congresses. This Prize was founded by the Government of Belgium and is awarded at meetings of the Congress to the author of the most striking paper submitted containing suggestions for promoting progress in construction, maintenance and exploitation of roads and for facilitating traffic. Four awards have been made previously. Dr. Rader's paper gave the results of investigations of the physical properties of asphalt pavements at low temperature.

J. M. DARKE, former Engineer, Materials Testing Laboratory, Lynn Works, who on August 31 retired from active duty after 46 years of service with the General Electric Co., was tendered a Friendship Party held in his honor and that of Mrs. Darke, at which were present all the employees of the Materials Testing Laboratory as well as a great many of the people who worked for Mr. Darke previously. Mr. Darke has represented his company membership in the Society since 1909 and has been very active in numerous phases of A.S.T.M. work especially in the work of Committee A-1 on Steel. Other committees of which he is a member include B-2 on Non-Ferrous Metals and Alloys and B-6 on Die-Cast Metals and Alloys. He is a charter member of the American Foundrymen's Assn., and has recently been awarded an honorary life membership. He is a former chairman of the Boston Chapter of the American Society for Metals and a member of the American Gear Manufacturers' Assn. Mr. E. N. DOWNING, Engineer, Materials Testing Laboratory, will continue the representation of this membership in A.S.T.M.

NEW MEMBERS TO OCTOBER 5, 1938

The following 40 members were elected from July 13 to October 5, 1938, making the total membership 4159:

Company Members (6)

ARUNDEL CORP., THE, Art Brown, Pier 2, Pratt St., Baltimore, Md.
CENTURY CEMENT MANUFACTURING CO., INC., A. J. Snyder, Treasurer and General Manager, Rosendale, N. Y.
COHEN AND SONS, JOSEPH H., Raymond Singer, Director of Research and Testing Laboratory, 71 Fifth Ave., New York City.
HONOLULU IRON WORKS CO., B. H. Eveleth, Manager, Building Materials Dept., Box 3140, Honolulu, Oahu, Hawaii.
NEW HAVEN COPPER CO., THE, E. S. Strang, Vice-President and General Manager, Seymour, Conn.
SYLVANIA INDUSTRIAL CORP., R. T. K. Cornwell, Chemist, Fredericksburg, Va.

Individual and Other Members (32)

ALLEN, S. E., President, C-O-Two Fire Equipment Co., 560 Belmont Ave., Newark, N. J.
FLOYD, F. D., Chief Chemist, Southern Kraft Corp., Box 216, Bastrop, La.
GELLERT, J. H., Superintendent, Nichol-Straight Foundry Co., 3174 Archer Ave., Chicago, Ill.
GEZELIUS, R. A., Metallurgist, Taylor-Wharton Iron and Steel Co., High Bridge, N. J.



GILLIES, K. S., Commissioner of Buildings, Building Dept., City of Toronto, City Hall, Toronto, Ont., Canada.

GOODMAN, H. W., Assistant Engineer, Ohio Department of Highways, Chillicothe, Ohio. For mail: Box 103, Lucasville, Ohio.

HILL, J. BENNETT, Manager, Development Division, Sun Oil Co., Marcus Hook, Pa.

INDIA, CHIEF INSPECTOR OF STORES AND CLOTHING, INSPECTORATE OF GENERAL STORES, C. O. Tattersall, Indian Army Ordnance Corps, Cawnpore, India.

KERR, J. C., Chief Inspector, The Wayne Pump Co., Fort Wayne, Ind. For mail: 937 Summit St., New Haven, Ind.

LENZ, W. J., Chemist, 1336 Starks Building, Louisville, Ky.

LEWIS, H. R., Chief Metallurgist, The Ohio Seamless Tube Co., Shelby, Ohio.

LONG, B. G., Director, Testing Laboratory, Ohio River Division, U. S. Engineer Office, Cincinnati, Ohio.

MARTIN, O. C., Manager, Nichols Copper Co., New York City. For mail: Box 1372, El Paso, Tex.

McBAIN, J. W., Professor of Chemistry, Stanford University, 571 Foothill Road, Stanford University, Calif.

METZ, H. E., Chief Engineer, Landers, Frary & Clark, Inc., New Britain, Conn.

MINELLI, J. J., Consulting Chemist, General Testing Laboratories, 7 W. Market St., Wilkes-Barre, Pa.

POLLITT, JOHN, Chief Inspector, Wilmot-Bredden, Ltd., Birmingham, England. For mail: 48 Westbourne Road, Olton, Birmingham, 27, England.

POWELL, E. BURNLEY, Consulting Engineer, Stone & Webster Engineering Corp., Boston, Mass. For mail: 20 Chapel St., Brookline, Mass.

RAFFENSPERGER, H. B., Architect, 800 Johnstown Trust Building, Johnstown, Pa.

ROLLER, P. S., Associate Physical Chemist, U. S. Bureau of Mines, College Park, Md.

SAUNDERS, H. F., Director of Research, The Sherwin-Williams Co., Titanium Division, Gloucester City, N. J.

SCHWALBE, H. C., Chemical Engineer, Mead Corp., 286 W. Water St., Chillicothe, Ohio.

SIMONS, W. R., President and General Manager, Simons Brick Co., 1195 S. Boyle Ave., Los Angeles, Calif.

SPALINGER, J. I., Industrial Lubricants Engineer, General Petroleum Corporation of California, Los Angeles, Calif. For mail: 644 W. Walnut St., Stockton, Calif.

STEILBERG, W. T., Consulting Architect, 85 Second St., San Francisco, Calif.

SWINEFORD, F. E., Chief Engineer, Bureau of Tests, Ohio State Highway Dept., Ohio State University, Columbus, Ohio.

TUEMMLER, F. D., Head, Analytical Dept., Shell Development Co., Fifty-third and Horton Sts., Emeryville, Calif.

VIGNAU, LAURENT, Chief de la Division du Controle des Fabrications, Société Nationale des Chemins de Fer Français, 100 Avenue de Suffren, Paris 15^e, France.

WAGNER, GERHARD, U. S. Representative, Mannesmannröhrenwerke, Dusseldorf, Germany. For mail: 233 Broadway, New York City.

WELLER, P. R., Supervising Principal, Jourden Diesel Schools, Inc., 2839 N. Broad St., Philadelphia, Pa.

WHITE, C. J., JR., Chief Engineer, Callaway Mills, Inc., Box 736, La Grange, Ga.

YETTER, G. L., Engineer, U. S. Bureau of Reclamation, Box 92, Coulee Dam, Wash.

Junior Members (2)

ELLIOTT, R. M., Research Engineer, The American Thermos Bottle Co., Norwich, Conn.

OHLGREN, H. A., Vice-President, Coates, Inc., 593 N. Snelling Ave., St. Paul, Minn.

NECROLOGY

We announce with regret the death of the following members and representative:

J. G. BERGQUIST, President, American Gas Accumulator Co., New York City. Member since 1904.

HENRY J. LUSS, Inspecting and Testing Engineer, Detroit, Mich. Member since 1924.

J. R. PAGE, Chief Material Inspector, Norfolk & Western Railway Co., Roanoke, Va. Mr. Page represented the Norfolk & Western Railway in its Society membership as well as on Committees A-1 on Steel, Subcommittee VII on Rolled Steel Wheels and Steel Tires; A-2 on Wrought Iron, Subcommittee II on Wrought Iron Bars; and A-5 on Corrosion of Iron and Steel, Subcommittees III on Inspection of Annapolis Tests and VI on Specifications for Metallic-Coated Products.

J. B. Young Dies

J. B. YOUNG, Engineer of Tests, Reading Company, died suddenly on July 30, succumbing to a heart attack. While he had not been in the best of health for some weeks, he was present and active at the 1938 Annual Meeting. The following resolution has been adopted by the Executive Committee in commemoration of Mr. Young, who had done so much for the Society:

Minute on the Death of

J. BERTRAM YOUNG

1876-1938

The members of the Executive Committee of the Society record their sorrow in the death on July 30, 1938, of J. Bertram Young, Engineer of Tests, Reading Company, Reading, Pa. Mr. Young's sudden demise came as a shock to his large number of friends and associates in Society work. A member since 1907, he had taken an active part in numerous committee activities and had completed a term as a member of the Executive Committee in June, 1938.

Mr. Young's technical education was obtained at the University of Pennsylvania where he received the degree of B.S. in Chemistry in 1897. Since 1907 he had been employed by the Reading Company, first as Chief Chemist and since 1918, as Engineer of Tests.

In the Society his outstanding work was in connection with Committees A-1 on Steel and A-2 on Wrought Iron. He was Secretary of Committee A-2 from 1912 to 1924, and Chairman, 1936 to 1938. Vice-Chairman of A-1 from 1924 to 1926, he became Chairman in the latter year and served three terms to 1932. His other committee memberships included D-1 on Paint, Varnish, Lacquer, and Related Products; A-3 on Cast Iron, and D-11 on Rubber Products. He was one of the original members of the latter serving from 1912, the year of its organization, to 1921. At the time of his death Mr. Young was a member of committee E-10 on Standards, his service on this committee beginning in 1934.

He was active in the work of the American Railway Engineering Association having served on its Rail and Water Service Committees and was one of the representatives in A.S.T.M. of this organization.

In his passing the Society loses one of its most loyal members, one who was very active through a long period of years and who was always ready to undertake work in its behalf. The Executive Committee extends its heartfelt sympathy to the members of his family and also wishes to record its deep appreciation of his many contributions and efforts for A.S.T.M.

Kent's Handbook on Design-Shop Practice

THERE has just been issued the second part of Kent's *Mechanical Engineers' Handbook*. The publication of this volume covering "Design-Shop Practice," makes the Handbook complete in two independent volumes, the first one covering "Power" having been issued in October, 1936. The volume on "Design-Shop Practice" includes some 29 main divisions starting with general properties of materials, and taking up various types of materials, followed by a section on strength of materials, in turn, by other portions devoted to fastenings, mechanical springs, bearings, gearings, control mechanisms, forging practice, foundry practice, wood-working, etc. A large staff of specialists contributed to the book, the editor-in-chief of which was R. T. Kent, son of the original editor of the Handbook. Many of the specialists are active in A.S.T.M. work.

This 1378-page volume, illustrated, page size 5 $\frac{3}{8}$ by 8 $\frac{3}{8}$ in., can be obtained from John Wiley & Sons, Inc., 440 Fourth Avenue, New York City, at \$5.00 per copy.



BULLETIN

October, 1938 . . . Page 55

PROFESSIONAL CARDS

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